Plan for evaluation of Austin Energy Green Building’s Multifamily Rating Program

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Abstract

Austin Energy Green Building (AEGB) started their multifamily rating program in 1999. It is a green building program where participants can receive different ratings, 1-5 stars, depending on how many requirements the building fulfills. AEGB wants to evaluate the projected energy and demand savings from the multifamily program to be able to report to Austin Energy at the end of the fiscal year.

Buildings going through the multifamily rating program can either use a prescriptive approach or a performance approach. For the prescriptive approach the savings are evaluated with the help of a deemed savings value. For the performance approach the participant needs to turn in an energy model of the proposed buildings with modeled projected energy and demand savings.

The purpose of this degree project was to develop a plan for evaluation of the projected savings from the multifamily rating program. AEGB will need to be able to compare the projected energy and demand savings with the actual energy and demand savings from the buildings that have gone through the program. Focus has been on finding a suitable evaluation approach, based on the available data. Criteria for inclusion were determined. Evaluation of all buildings is not be possible and therefore a sample size needed to be determined for the population. The projected energy savings data was analyzed. A way to account for apartments without full year use data was studied as well as common criteria for uncertainty analysis.

It was suggested that one year of full energy use data was enough as criterion for buildings to be a part of the population to be evaluated, which gave a population size of 29 buildings. 86 % of the buildings received a 1-3 star rating and they account for about 4,960 $MWh$ or 96 % of the projected energy savings. If a simple random sample is used with a confidence level of 90 % and 10 % relative precision the sample will be 21 buildings. If the relative precision is changed to 20 % the sample will contain 11 buildings. Another option is to use stratified random sample, and sample sizes were calculated by star rating and size of the buildings. A number of different ways of accounting for vacant units were found however the latest vacancy rate for multifamily
buildings in Austin was 4%. This corresponds to about 205.9 MW·h in lost projected energy savings for the buildings that have gone through AEGB’s multifamily program. Lastly, post occupancy evaluation (POE) will be recommended for this evaluation effort of AEGB’s multifamily program.
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**List of acronyms**

AEGB: Austin Energy Green Building

AMY: Actual Meteorological Year


CBECs: Commercial Building Energy Consumption Survey

CDD: Cooling degree day

CEE: Consortium for Energy Efficiency

DD: Degree day

DOE: U.S. Department of Energy

ECM: Energy Conservation Measure

EIA: U.S. Energy Information Administration

EM&V: Evaluation, Measurement and Verification

EPA: The Environmental Protection Agency

EUI: Energy Use Intensity

EVO: Efficiency Valuation Organization

FPC: Finite Population Correction

Gpm: Gallons per minute

Gpf: Gallons per flush

HDD: Heating degree day

IECC: International Energy Conservation Code

IPMVP: International Performance Measurement and Verification Protocol
LEED: Leadership in Energy and Environmental Design

M&V: Measurement and Verification

NREL: National Renewable Energy Laboratory

POE: Post Occupancy Evaluation

RCT: Randomized Controlled Trial

SEE Action: The State and Local Energy Efficiency Action Network

SEER: Seasonal Energy Efficiency Ratio

TMY: Typical Meteorological Year


UMP: Uniform Methods Program
1. Introduction

Buildings are an essential part of our society today emphasized by the fact that Americans on average spend 90% of their time indoors[1]. In 2011, the residential sector in the United States stood for 6.8% of the use of primary energy and of 22% of the final energy use [2]. This corresponds to 6.6 and 21.6 quadrillion Btu's respectively [2]. The building sector accounts for over 20% of the delivered energy use worldwide and according to the U.S. Energy Information Administration (EIA) it is predicted to be the fastest growing sector energy wise in the coming years [3]. As more people move from rural to urban settings, electricity usage will increase and hence the energy demand in the world is expected to grow [3]. A majority of the fuels that will be needed for this increase in energy demand will come from fossil fuels. Fossil fuels will in turn increase the $CO_2$ levels in the atmosphere, which have been related to both global warming and climate change [3].

1.1. Background

The electrical utility company in Austin, Austin Energy, is trying to reduce the peak energy demand in the city by 800 MW by 2020, to avoid the need of a new power plant [4]. One way to lessen the effects from new buildings on the environment and to provide healthier indoor climate for human beings is constructing buildings from a sustainable approach [5]. One such approach is green building and these buildings are designed to [6]:

- Efficiently use energy, water and other resources
- Protect occupant health and improve employee productivity
- Reduce waste, pollution and environmental degradation

The city government of Austin, Texas started the nation’s first Green Building Program for Single family houses in 1990 [7]. Its mission is to help the building industry transform into a sustainable future. The department responsible for the green building programs is Austin Energy Green Building (AEGB), who reports to Austin Energy. Today they have three green building rating programs. One, as mentioned earlier for single family buildings. A second for multifamily buildings, which when it started in
1999, was the nation’s first multifamily rating program, and third a commercial rating program. Buildings that participate in the rating program can achieve different levels of rating; 1-5 stars, depending on how many requirements the project meets. These requirements will be presented in Chapter 4. It is important to note that The Green Building Rating Program is not an incentive program where participants receive rebates, but can be likened to Leadership in energy and environmental design (LEED) [8] which is another green building program in the U.S.

Evaluation, measurement and verification (EM&V) is used to evaluate the projected savings from an energy efficiency program. The results can be used to improve existing and future programs and methods to calculate savings estimates. Studies have found that the projected energy use for programs overall correspond fairly well with the actual energy use after the program has been implemented [9, 10]. However, the studies also found that the energy use for the individual projects in the program had varying correspondence to the actual energy use[9, 10]. For example, one study where post occupancy evaluation (POE) was undertaken on 100 LEED-certified buildings found that they on average use 18 – 39 % less energy than buildings built to code. The same study also found that 28 – 35 % of the LEED-certified buildings use more energy than similar buildings built to code [11]. The practice of EM&V is becoming more common and is a way to validate the accuracy of the projected savings for an energy efficiency program. One issue with trying to measure energy and demand savings is that one cannot measure the absence of something, in this case energy use [12]. This is called the counterfactual scenario, where the savings are calculated as how much energy would have been used without the energy efficiency program in place relative to how much is being used with it in place [12]. It is important to note that these savings are in fact saving estimates [12]. Another question that arises with evaluation of an energy efficiency program is “How good is good enough?”. This is another way of asking what level of certainty is needed for the evaluation and also how well that level of certainty is balanced with the cost of the evaluation measures needed to reach that level of certainty [12]. It is recommended that the budget for EM&V should not exceed 10 % of the value of the estimated annual savings [13].
Due to the lack of standards for how to carry out an evaluation of an energy efficiency study today, different states and local authorities have developed their own evaluation systems to fit the programs they have in place [14]. This has led to a lot of different approaches as how to evaluate energy savings and the results are therefore not always comparable between different sites. This area is getting more attention and there have been some efforts to create guidelines that can be followed to create more coherent industry approaches. The goal is to increase the consistency and transparency of evaluation of energy efficiency programs so the field will gain more credibility [14]. One of these is the U.S. Department of Energy (DOE) and The Environmental Protection Agency’s (EPA) project The State and Local Energy Efficiency Action Network (SEE Action). They have developed the Energy Efficiency Program Impact Evaluation Guide, an attempt to spread standard evaluation terminology, structures and best practice approaches. They hope this will support further adoption of energy efficiency and help the field grow [12]. Another project is the U.S. DOE’s Uniform Methods Project (UMP) which is developing protocols with straightforward methods for EM&V of some common energy efficiency measures and programs in the U.S [15]. For evaluation of energy and demand savings for energy efficiency projects and measures there are two commonly referenced guidelines. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) came out with “Guideline 14 – Measurement of energy and demand savings” in 2002 [16]. And in 2012 The Efficiency Valuation Organization (EVO) released their “International Performance Measurement and Verification Protocol - Concepts and Options for Determining Energy and Water Savings Volume” (IPMVP)[13].
1.2. Purpose and goal

The purpose of this degree project is to develop a plan for EM&V of the projected savings from AEGB’s multifamily rating program. The plan needs to be developed so that AEGB can compare the projected energy use and demand with the actual energy use and demand of the buildings. Hopefully this will prove to be within the desired certainty level defined in the evaluation plan. If this is not the case, the evaluation plan can be used as a first step and insight to a methodology for setting a new deemed savings value. Deemed savings are stipulated values for a specific energy efficiency measure. It may be developed from data sources, technical reference sheets or for example energy models. The values have not been measured at the site but are regarded as being able to represent the measure in the situation being evaluated.

The focus will be on verifying the accuracy of the multifamily programs energy and demand savings over the whole population and not the savings from individual buildings. Therefore a sampling protocol has to be established to decide how many buildings will need to constitute a sample to reach a desired certainty compared to how much work needs to be invested. The sample should be representative for the program and will also be used to compare the projected energy savings for the whole program with the actual energy savings. When evaluating savings a baseline needs to be defined. This baseline for energy savings is dependent on independent variables. One common independent variable is occupancy and the focus will be on finding a way to eliminate apartment units without full year use data. This is because all buildings were assumed to be fully occupied when the deemed savings value was determined. This may not be the case in real life and during the years some apartments have likely been vacant for shorter or longer periods of time. If AEGB knows how many apartments were vacant during the reporting period they can recalculate the projected savings. This will result in a more accurate evaluation of the deemed savings value.

This plan will be developed through studying available data from AEGB as well as a literature study of reports, guides and protocols for best practice in the industry.
1.3. Limitations

This degree project does not include plans for the single-family program nor the commercial program. Implementation of the plan is not included nor is further steps to reevaluate today’s processes in case the criteria for accuracy of the evaluation are not fulfilled.

This project will only study the energy and demand savings for electricity. The energy savings for gas will not be examined since they are attributed to another utility company, Texas Gas.

At the time of this degree project only projected energy and demand savings data was available. Utility data from Austin Energy was yet to be obtained and therefore only the projected savings data has been studied.

Typical Meteorological Year (TMY) data was used for the model that AEGB used for their deemed savings calculations for a typical multifamily building. AEGB will receive utility data from Austin Energy for the buildings in the selected sample. The utility data will be compared to the projected savings which are based on the deemed savings value. For the comparison of the two sets of data to be consistent the utility data will need to be adjusted to a typical year [9]. Temperature as an independent variable and TMY will be explained in Section 3.6.1. However, Austin Energy will adjust the data before turning it over to AEGB and therefore the influence of weather will not be studied further in this degree project.

The scope of evaluating energy efficiency programs is a broad term and incorporates a number of different programs. These can be incentivized programs for certain measures such as lighting, or other retrofit measures, behavioral and educational programs or like in this case, green building rating programs. Therefore a lot of concepts are not going to be evaluated, such as net program savings, which take into account free-ridership and program spillover, effects that cannot be completely attributed to the specific program. This project will not take into account non-energy benefits for example, reduced line losses, reduced air emissions, reduced water use, better indoor air quality etc. even though these measures are part of AEGB’s Multifamily rating program. This project will
focus solely on evaluating the projected energy and demand savings attributed to this program.

1.4. Methodology

AEGB provided projected energy data for all the multifamily buildings from fiscal year 2008, to date. This data is what has been analyzed in this degree project and is also the data which the final sample of buildings is based on. The information on the issues to be studied was gathered from a number of different sources, first and foremost through literature review but also webinars and discussions with relevant people with knowledge in the field. The protocols and guides that have been studied were all written by acknowledged branch organizations or government facilitated efforts and projects. Therefore the guides and protocols are seen as reliable sources based on good theoretical grounds. Besides the guides and protocols many research articles have been studied.

Other sources of information for this degree project has been webinars from Noesis Energy, an online energy measurements and savings platform[5], on “Calculating Savings (M&V) for Energy Efficiency Projects” on January 23rd 2014 and “Calculating Weather-Normalized Baselines” on February 5th 2014 and April 3rd 2014. SEE Action also have multiple webinars available on their website and a few of these have been consulted on subjects such as deemed savings, energy codes and standards and an overview of the Energy Efficiency Program Impact Evaluation Guide [17].
2. Literature review

Zuo and Zhao performed a review of green building research and studies. The review showed that there have been many studies of green buildings the last decade and that green building is seen as a measure that can help lessen the effects of buildings on the environment, society and economy [18]. The review also found that there is a lack of assessment of the real performance of buildings and that assessment tools will need to be developed. The real performance of the buildings is suggested to be further studied through post occupancy evaluation (POE). It was also found that the majority of buildings being studied today are office buildings and Zuo and Zhao suggest that future studies should focus more on residential buildings [18].

When studying the energy use of a building, occupancy is one variable that may have a large influence. Occupancy can be seen from two different perspectives, as occupant behavior or as occupancy presence [19]. Occupancy presence can be defined in many different ways such as number of occupancy hours, weekdays/weekend occupancy or occupancy rate [13]. Occupancy presence can change hourly, daily, weekly and seasonally [16]. It is important to determine the level of occupancy in buildings, such as offices and homes, to be able to determine the energy efficiency of measures as well as energy use and performance of the building. It is also of interest to know how the occupancy levels change over time, for example when tenants in multifamily buildings leave to go to work or go on vacation [20]. When carrying out simulations certain assumptions has to be made about for example occupancy schedules, plug loads due to occupancy and the occupants acceptance of new technologies [21]. Stoppel and Leite states that a majority of energy models account for occupancy presence through predetermined schedules. These schedules usually vary depending on if it is a weekday or the weekend. Occupancy behavior is usually modeled with the help of plug-load factors. However, these energy models does not account for variations in occupant behavior and presence [19]. Assumptions have to be made but are often optimistic. Occupants may spend more time in the building than predicted with the schedules or they may set the air conditioning or heating to other temperatures than what was simulated [22]. It can be difficult to predict occupant behavior when carrying out the simulations. Therefore when carrying out evaluation, measurement and verification
(EM&V) it may be possible to see what areas that are not operating as predicted in the simulation of the building. And with occupant and operator training these differences can be addressed.

Haberl, et. al. found that occupancy behavior was the most significant variable when it came to actual energy usage [23]. They compared the energy performance of two identical houses in Houston, one with energy efficiency upgrades and one built to code. The energy efficient home used more energy than the standard home. This was because the family living in the energy efficient house let the air conditioner run at all hours of the day and kept the same temperature daytime and nighttime. The family living in the standard house turned off their air conditioner or raised the temperature on the thermostat whenever they left the house or went to bed [23]. Occupancy is the independent variable affecting energy use that is most difficult to foresee [24]. Occupants’ not behaving as predicted is another reason why the projected energy usage does not correlate with the actual energy usage [23, 24].

Stoppel and Leite examined the fluctuation in occupancy, in a military dormitory, by studying the water data from the building together with reported occupancy from the building manager [19]. The electricity use may not fluctuate much when occupants are absent for shorter periods of time, due to plug loads from example refrigerators and other appliances. However, for apartments the water usage is likely to be close to zero when the apartment is unoccupied. Stoppel and Leite found that the reported occupancy did not account for when tenants leave for longer periods of times, but that it could be detected by looking at the water data [19]. Tonn et. al. performed a study on energy models of multifamily buildings in Tacoma [26]. They suggest that when studying building-level energy use and savings the issue of vacancy needs to be taken into account [26]. This is because vacant apartment units may draw cool or heated air from adjacent apartments and thereby increase the cooling and heating load for those apartments [26]. The report presents a way to account for vacancy rate and a way to calculate the occupancy rate. At the time of the study, the county where Tacoma is situated, Pierce County, studied the vacancy rate of apartments in the county. They did so by defining the vacancy rate as all apartments that were vacant the first week of the month. This may be misleading as apartments can be occupied during other parts of the
month. Also apartments may become vacant later during the month [26]. Tonn et. al. developed an approach to calculate occupancy rate by dividing “occupied unit-days” by “total unit-days”. Utility bills were gathered for most apartments in the study and vacant units were deemed to be the units that had very low electricity use. These were identified as the apartments that had an electricity use of 50% of the lowest base load found in the multifamily building. The “occupied unit-days” were calculated as all days that an apartment was occupied during a month. Further the “total unit-days” were calculated as the number of units in each multifamily buildings times the number of days of the month [26].

In Austin, Capitol Market Research has been surveying the apartment market since 1991 [27]. All multifamily buildings surveyed are rentals. They publish the “Austin Apartment Market Summary” biannually, in June and December [28]. Capitol Market Research has categorized the occupancy into three groups; overall occupancy, new construction occupancy and newer buildings where occupancy has had time to stabilize. New constructions are identified as buildings that were built during the past year from when the survey was conducted. The overall occupancy rate for apartments in Austin was 97.3% in June 2013 [29] and decreased to 96.9% in December of 2013 [30]. Figure 1 shows the overall occupancy rates in Austin from June 2008 until December 2013. During 2008 and 2009 the occupancy rates were noticeably lower, with a low of 89.5 % in June 2009. Erin Roberts at Capitol Market Research explained that this was because a lot of new apartments reached the market at the same time as the financial crisis was at its height. During the past 3 years, 2011 through 2013, the overall occupancy rate has been steady between 96% and 98%.

The occupancy rate for new construction went from 79.6% during the first half of 2013 [29] to 78.2% during the second half [30]. For newer buildings where the occupancy has had time to stabilize, the occupancy rate was 95.4% during the first half of 2013 [29] and 96.6% during the second half [30].
Figure 1 The occupancy rate for multifamily buildings in Austin from June 2008 through December 2013 [28].

By using the American Fact Finder on The U.S. Census Bureau’s website a summary of the housing characteristics in Austin between 2008 and 2012 was found. During this time the estimated rental vacancy rate was 1.7% [31], which corresponds to an occupancy rate of 98.3%.

Another variable that may have significance for the energy use is time. Danielski conducted a study of large variations of specific energy use of environmentally friendly buildings in Stockholm [32]. He found that the most significant variable for the variations was the time that elapsed from when the building was built to when the energy performance of the building was evaluated [32]. For the energy use to stabilize Danielski found that it was best to wait 2 years to evaluate the buildings. For buildings that were evaluated before the 2 year mark, changes up to 34% in the specific energy use was observed over time [32].
In Austin peak electrical power demand occurs during the summer and the outdoor temperature is usually above 38°C (100°F) during the peak hour [33]. Further Austin Energy is trying to reduce the peak demand by 800 MW by year 2020 in Austin [4]. Rhodes et. al. studied data from energy audits of 4,971 single family homes in Austin and found it was common that air-conditioners are underperforming, due to factors which include oversized systems and inefficient duct work [33]. On a utility scale inefficient air-conditioners can have a substantial effect on the peak demand [33].

Another energy use issue is when the equipment installed is not installed correctly and operations personnel are not educated on how to operate the new equipment. One example is a POE study performed by National Renewable Energy Laboratory (NREL) of 6 high performance buildings. In all 6 buildings the daylight sensors did not function properly together with the lights. After the buildings were occupied the sensors had to be reinstalled and reprogrammed [22].
3. Theory
This chapter will go through some of the fundamental concepts of evaluation, measurement and verification (EM&V) as well as some of the concepts that are important for this particular evaluation effort.

3.1. Savings estimates
When an energy efficiency measure is installed, the savings related to this measure are usually called energy or demand savings. This term can be misleading because these energy savings cannot be directly measured; there is no way of measuring the absence of energy [13, 16]. What can be measured is how much energy that was used before the energy efficiency measure was installed and how much energy that is used after it is installed. After adjustments have been made, for example weather, the two can be compared and how much energy was saved can be estimated. Thus it is not possible to measure the absence of energy use, and this is why the savings should be called savings estimates [12].

3.2. Demand and Demand savings
Demand is defined as “the time rate of energy flow” [12] and is commonly measured in the SI unit kilowatts [kW]. An example of peak demand is in warm climates when the warm afternoon comes around and all air conditioning units are on to be able to keep the desired indoor temperature. This usually happens at the same time for everyone in a certain geographical area and therefore the electrical company needs to be able to meet this peak demand. Demand savings are the savings attributed to an energy efficiency measure that reduces the need of energy demand. Demand savings can be estimated in a number of different ways. It can be defined as annual demand savings, where the average demand for the whole year is estimated. It can also be peak demand savings, where the savings during the peak of the whole year or a specific season is studied [12].

3.3. Savings evaluation approaches
There are practically three ways of evaluating energy and demand savings for energy efficiency programs [12]; deemed savings, measurement and verification (M&V) and large scale consumption data analysis. Deemed savings are stipulated values for energy
and/or demand savings that are based on historical data [12]. The savings values have normally been measured and verified for the energy efficiency measure in similar studies and can usually be found in databases [34], so called technical reference manuals (TRM) [12]. Deemed savings are common when the evaluation budget is low and for projects where the uncertainty about the stipulated values can be assumed to be low. Deemed savings can preferably be used for energy efficiency measures that are well-defined [12].

Large scale consumption data analysis is a way of determining savings estimates through comparison of utility data. Utility data from participants in the program who have carried out the energy efficiency measure is compared to a control group of buildings with similar characteristics who have not carried out the measure [12]. The most common control group studies are randomized controlled trials (RCT) and quasi-experimental methods [12].

### 3.4. Avoided energy use and normalized savings

Avoided energy use is a way of calculating savings with the reporting period as basis [13]. To do this the baseline conditions need to be adjusted to account for conditions that were present during the reporting period. These conditions can be independent variables such as weather and production levels and static factors such as building size and type of occupants. Savings calculated as avoided energy use, even though they are adjusted for weather conditions, are savings that reflect the actual weather conditions during the reporting period [13].

Normalized savings is a way of calculating savings with fixed conditions as basis. The conditions can be chosen for a desired period such as the baseline period; or any other desired period. The conditions can also be defined as some set of normal or average conditions [13]. This way both the baseline period and the reporting period may have to be adjusted to the fixed conditions that have been chosen. When using normalized savings the calculations can be carried out for any time period as long as it is adjusted for the same fixed conditions. This means that savings can be calculated for more than one period and evaluating savings for one or multiple years is possible [13].
3.4.1. Projected, claimed and evaluated savings

Projected savings are the savings that a program administrator or implementer reports before an energy efficiency measure has been implemented. These savings are estimates of how much energy will be saved after carrying out the project, which can be of interest when planning an energy efficiency project. The projected savings can also be called “ex ante savings” [12].

When the energy efficiency measure has been carried out the administrator or implementer can report claimed savings. To estimate these savings the program can use their own staff or a consultant [12]. Claimed savings may build off of the projected savings but can be adjusted for facts that came up during the implementation of the measure. During the implementation changes may have been made in regard to equipment specifics or perhaps some energy efficiency measures that were planned never got implemented. Therefore the claimed savings may be different from the projected savings. Claimed savings can also be referred to as “reported savings” [12].

Evaluated savings have been verified by a third-party evaluator. The evaluator can for example collect his own data to independently carry out the evaluation [12]. The evaluator can also conduct site visits to make sure that the reported amounts of measures have been installed. The evaluator can use savings values reported by the implementer/administrator, use values from the manufacturer or meter data to estimate the savings. Evaluated savings can also be called “ex post savings” [12].

3.5. Sample design

When evaluating an energy efficiency measure, a project, a program or a portfolio of programs the group of participants can be large. To reach the most reliable and accurate result, evaluating the whole population would be best. However doing this can prove to be expensive, even for small populations and therefore it is common to evaluate a sample of participants and let the sample represent the whole population. Evaluating a sample can of course lead to skewed results but it is important to remember that evaluation of energy efficiency programs has to be cost effective and the cost of evaluation should be weighed against the accuracy of the evaluation[12, 13].
3.5.1. Simple random sample (SRS)

When a population is homogenous a simple random sample is preferable [36]. Simple random sample is the simplest way of determining a sample. A sample is simply picked randomly out of the whole population. Each member has the same probability, \( n/N \) to be selected for the sample, where \( n \) is the sample size and \( N \) is the population size [36].

The initial sample size can be calculated with the help of a desired level of precision and a desired confidence level [36]. The initial sample size is calculated with the following equation:

\[
    n_0 = \left( \frac{z \cdot CV}{e} \right)^2
\]

Where:

- \( n_0 \) is the initial sample size
- \( z \) is the standard normal distribution value for an infinite number of readings and a desired confidence level
- \( CV \) is the coefficient of variance
- \( e \) is the desired precision

For the initial sample size the coefficient of variance is usually assumed to be 0.5 [13, 36]. This should be adjusted later when the real CV is known [13, 36]. If similar studies that have been carried out before, the CV from that study can be assumed to be representative for the current study and the value can be used to estimate the initial sample size [13, 36].

When looking at smaller populations it can be beneficial to account for the finite population correction (FPC). Since the calculations of the initial sample size is only based on statistical parameters the initial sample size can end up being larger than the actual population being evaluated. It can also result in the initial sample size accounting for a large part of the population. If the population that is being evaluated is less than 20
times the calculated initial sample size, the sample size can be adjusted with FPC. The FPC accounts for the fact that when a population size is small, i.e. the sample size accounts for a large part of the population; it reduces the uncertainty for the population mean [36].

To calculate the sample size for a small population, first calculate the initial sample size with equation (1) then adjust the sample size with the FPC with the help of the following equation:

\[
    n = \frac{n_0 \cdot N}{n_0 + N}
\]

Where:

- \( n \) is the sample size after adjusting the initial sample size with the help of the finite population correction.
- \( n_0 \) is the initial sample size
- \( N \) is the population size

### 3.5.2. Stratified random sample

When a population is heterogeneous a stratified random sample is preferable. In a stratified sample the population is first divided up into categories that are suitable for the particular study, so called strata. For example, if projected saving values are available for all participants the population can first be divided into groups depending on the size of the savings and then a random sample can be chosen from each group[36]. Using stratified random sampling can decrease the variance, since each stratum will be more homogeneous than the whole population. When a population is small and simple random sampling is used parts of a heterogeneous population may not be represented. Dividing the population into strata will ensure that all categories are represented in the final sample [36].

To calculate a stratified random sample equation (3) and (4) may be used [37]. If the coefficient of variance is assumed to be the same for all strata, the total sample size as
well as the strata sample sizes will be proportional to the projected energy savings for each stratum.

$$n = \frac{[\sum_i (kWh_i \cdot CV_i)]^2}{[\frac{e \cdot kWh_T}{z}]^2 + \sum_i \frac{(kWh_i \cdot CV_i)^2}{N_i}}$$  \hspace{1cm} (3)$$

Where:

- $n$ is the total sample size
- $kWh_i$ is the projected energy savings for group $i$
- $CV_i$ is the coefficient of variance for group $i$
- $e$ is the desired precision
- $kWh_T$ is the projected total energy savings
- $z$ is the standard normal distribution value for an infinite number of readings and a desired confidence level
- $N_i$ is the population size for group $i$

Equation (3) takes the size of the population into account and therefore adjusting the sample size with FPC is not necessary. To calculate the sample size for each strata Equation (4) may be used.

$$n_i = n \left[ \frac{kWh_i \cdot CV_i}{\sum_i kWh_i \cdot CV_i} \right]$$  \hspace{1cm} (4)$$

Where:

- $n_i$ is the sample size for group $i$
- $n$ is the total sample size
- $kWh_i$ is the projected energy savings for group $i$
$CV_i$ is the coefficient of variance for group $i$

### 3.6. Baseline

When estimating savings the energy use has to be compared to what would have been if the particular program had not been in place. This is because a building has to be participating or not participating in a program at any given moment [12]. Therefore to be able to estimate savings a baseline has to be defined as the condition for when the program was not yet implemented.

![Figure 2: The energy usage before, during and after an energy efficiency project has been installed][12]

Figure 2 shows how a baseline can be defined. On the left side of the green area, that illustrates the time of installation of an energy efficiency measure, the baseline energy use has been documented, either through independent measurement or utility data. This is called the baseline period. The line continues on the right side of the green area and represents how much energy is being used after the installation. This is called the reporting period. The reporting period data can also be measured or taken from utility bills. The green dotted line represents how much energy the participant was estimated to use in the case that they had not participated in the program. Hence, the blue shaded area represents the estimated savings [12].
If a study has a control group, the baseline is defined as the energy use and characteristics of the control group [12]. This works best for studies with large datasets. For deemed savings and the M&V approach there is no control group and the baseline has to be determined in another way [12].

3.6.1. Independent variables
When defining a baseline scenario there are a number of variables to take into account. The independent variables are variables that will affect the baseline; hence the baseline is the dependent variable in this case. Independent variables are variables that are expected to change regularly during the baseline and reporting period [13]. To determine if an independent variable has an important effect on the energy use and hence the baseline a t-test can be carried out [16]. A t-test is a statistical test and will be discussed further later in this chapter. All independent variables that are suspected to have a substantial effect may be tested and all variables that pass should be included in the baseline [16]. Weather or temperature and occupancy are two independent variables that are often considered to have an influence on buildings’ energy use and demand [16].

Temperature
Weather varies from year to year. Weather phenomena that influence the energy use and demand for buildings are temperature, humidity, cloud cover and wind [16]. The outdoor temperature is known to have a substantial effect on the energy use in buildings and is often the most important independent variable that influences the baseline [16]. When it is cold outside buildings need to be heated and when it is warm outside buildings need to be cooled and the temperature difference can be illustrated by Equation 5:

\[ \Delta T = T_{out} - T_{in} \]  

One way to quantify how much a building need to be heated or cooled over a specified period of time is by using degree days (DD). Degree days are defined as the temperature difference between the daily mean outside temperature and a specified reference
temperature, which is a balance point temperature [38]. The balance point temperature is commonly set as the outside temperature where neither heating nor cooling of the inside is needed. It is commonly set at 65°F which is equivalent to 18.3°C [38]. In buildings where both cooling and heating are possible there are two different metrics that are of interest, cooling degree days (CDD) and heating degree days (HDD) [38]. Cooling degree days correlate to the days when the outdoor temperature is higher than the balance point temperature and cooling of the indoor air is needed. Heating degree days correlate to the days when the outdoor temperature is lower than the balance point temperature and heating of the indoor air is needed [38].

Typical meteorological year and actual meteorological year

A typical meteorological year (TMY) data is a collation of weather data for a specific location for a time much longer than a year in duration. The data is selected so that it shows weather phenomenon occurring in the specific area and at the same time shows long time averages for the location. Data is collected from weather stations, most of them located at airports [39]. The data is used for simulations and energy models. When using a typical meteorological year the estimated savings will be normalized savings [13]. When simulating energy models with TMY data it is important to remember that the data does not show the extremes. If the systems being simulated need to be sized for extreme conditions, caution should be taken if TMY data is used for the simulations [39].

To account for actual performance of a building, actual meteorological year (AMY) data needs to be used [39]. AMY data is a set of hourly weather data that can be found for the desired time period, for example the resent year. With this data the actual effect of the weather on the energy use and demand of the building can be accounted for [13].

3.7. Uncertainty and sensitivity analysis

There are a number of different factors to take into consideration when determining the accuracy of the results. Uncertainty is a way of expressing the accuracy of a result in a statistical correct manner [13]. The uncertainty of the result also has to be weighed against the cost of the evaluation [12].
3.7.1. Systematic errors

Systematic errors are errors not happening due to chance. They are errors that happen because someone made a certain decision and the systematic errors therefore results in biased results [12]. The results are systematically underestimated or overestimated. There are a few ways in which systematic errors can occur, for example uncertainty associated with measurement and modeling. Systematic errors can also be a result of how data is collected [12]. For example if some part of a population is excluded from a sample for some reason this may lead to missing data for the part of the population that is excluded. This gives a biased view of the population as a result of so called non-coverage errors [12]. Self-selection is also a source of systematic errors. This occurs when for example a survey is sent out and some people choose not to answer the survey [12].

Uncertainty associated with measurement

When evaluating savings from energy efficiency programs some parameters likely needs to be metered. No meter is 100 % accurate and the uncertainty for the metered results can usually be retrieved from the manufacturer [16]. Meters have usually been tested in laboratory settings and therefore the uncertainty of the results may be higher when the metering equipment is used out in the field [13]. It is also important to place the meters in the right place to make sure the right sort of information is being measured and monitored [12]. The data retrieved from the meters also need to be checked continuously which requires knowledgeable personnel [12].

Uncertainty associated with modeling

When using a model to predict results there are a number of ways errors can occur which increase the uncertainty with the model being used [12, 13]. The wrong type of model may be used, for example assuming the wrong functional form for the study at hand [12, 13]. Inclusion or exclusion of relevant independent variables can also represent a large error associated with modeling. For example, only accounting for weather when occupancy also has a major influence on the energy use and demand of a building would be a misrepresentation of the parameters that are needed to model the energy use. On another note, caution should be taken to not include independent
variables that are not relevant for the study. This can result in an overly complex model which can be both expensive and time consuming [13]. Another reason for uncertainty is when the model is based on insufficient data [13].

3.7.2. Random errors
Random errors are errors that occur due to chance [12]. There are many scenarios that can lead to random errors in the results. Some of these scenarios are if the weather is unusually cold or warm, if a company hires more people or if a family goes on vacation. All of this will lead to changes in the energy use and demand but it can be difficult to predict and the changes may go by unnoticed [12]. When a program is being evaluated the program administrators’ wants to know if the changes or savings were due to the program. But there is a risk that changes due to random errors are a part of the reported savings. Therefore the results are usually presented with their related precision and confidence level [12].

Uncertainty associated with sampling
One common source of random errors is when the evaluator cannot carry out measurements on the whole population. This may be due to budget constraints, or a large population that will make measurement of all participants time consuming and expensive [12]. Even if a random sample is selected, there will always be random errors associated with the sample. Even if the whole population would be metered, the risk of random errors would still be present in the form of unobserved variables [12]. One way of limiting the uncertainty of random errors due to sampling is to increase the sample size. With a larger sample size the room for random errors gets smaller and the uncertainty of the results decreases [12]. The standard error is said to be inversely proportional to the square root of the sample size. If the sample size is increased by a factor $f$, the standard error will be reduced by the square root of factor $f$ [13].
4. Austin Energy Green Building’s Multifamily Rating Program

Austin Energy is a publicly owned electric utility that serves the Greater Austin area and about one million electric utility customers [40]. Electric utility customers within the Austin city limit and some additional areas outside the city limit only have the choice of Austin Energy as electric utility company. Austin Energy is the country’s 8th largest publicly owned utility and some of its profits go to the City of Austin to supplement some of their other departments and programs financially [40]. Austin Energy is working on reducing the energy use in Austin through different energy efficiency and demand response programs. Between 1982 and 2006 Austin Energy’s energy efficiency measures removed the need of building a new 700 MW power plant [40]. Austin Energy’s new goal is to offset the need of building a 800 MW power plant by reducing the peak demand by 800 MW between 2007 and 2020 [40]. Austin Energy Green Building (AEGB) is the department at Austin Energy that oversees the Single family, Multifamily and Commercial Rating Programs.

4.1. About the program

As mentioned in Section 1.1., AEGB’s Multifamily Rating Program was started in 1999. When it was started it was the first multifamily rating program in the U.S [7]. The program is a green building program which supports more measures than just energy efficiency measures [41]. Another equivalent green building program is the Leadership in energy and environmental design (LEED) certification program which is wide spread over the U.S [8].

AEGB’s rating programs give them an opportunity to address local issues and to incorporate City of Austin’s environmental protection goals [42]. It also gives AEGB a chance to try out new standards that can later be incorporated into City of Austin’s energy and building codes. With these measures AEGB can fulfill their mission: “To lead the transformation of the building industry to a sustainable future” [7].

Participants that want to rate their building are encouraged to contact AEGB early in the planning process. This way the participating team can plan and design the building
around the requirements from the start [41]. The participant is required to report to AEGB throughout the process, from the design and planning phase, through the construction phase and finally the close out phase. After this the participating building will receive an applicable star rating. The multifamily rating program is designed for new construction and major renovation projects [41].

Up to the beginning of the year, January of 2014, 101 buildings have received a rating from AEGB’s multifamily rating program. Most of the participating multifamily buildings are rentals but a few (4 out of 39 from November of 2008 until January 2014) are condos for sale. These condos account for 2% of the total apartment units, 2% of the total square footage and 1% of the total projected savings. According to Richard Morgan at AEGB the majority of low-rise multifamily buildings receiving a rating are rental properties. However, among high-rise multifamily buildings the majority are condos. To get a feeling for how many apartments in Austin go through AEGB’s multifamily rating program each year; AEGB compares how many apartments are permitted each year with how many buildings receive a star rating. However, AEGB only give out ratings to finalized buildings and there is usually a gap of about 2-3 years from when a building is permitted to when it is built and can receive a star rating from AEGB. Based on these assumptions approximately 20-25% of all buildings in Austin receive a star rating from AEGB each year.

**4.2. Star-ratings and requirements**

Participating buildings in the Multifamily Rating Program can receive 1 to 5 stars depending on how many requirements the project fulfills. All projects must fulfill some basic requirements. When the basic requirements are fulfilled the building receives a 1 star rating [41]. To receive a higher rating the project can earn points within a range of fields associated with green building which are presented in Table 1. Participants have a choice of following a prescriptive path and since 2 years back there is also the option of following a performance path. Participants following the performance path are required to turn in an energy model of the building, showing a certain percentage of lower energy use than the baseline model for the building. The performance path gives the building owner more flexibility in how to design the building. For the prescriptive path building
owners are restricted to follow the guidelines in the 2013 Multifamily Rating Guidebook [41]. But for the performance path they can choose the design of for example window/wall ratios, HVAC system and other building features.

This program is applicable to all multifamily buildings that are that are 2 to 6 stories intended for residential or mixed-use purposes [41]. Mixed-use areas are for example when the ground floor of a building is being used for retail and offices and the rest is used as residential units. Multifamily buildings taller than 6 stories can apply under the Commercial Rating Program [41]. This is because the building code changes for buildings taller than 6 stories and they are required to have concrete and steel constructions instead of wood frame constructions.

Buildings that are 2 to 3 stories, are considered to be low-rise buildings, are required to follow the residential section of the City of Austin energy code. Buildings 4 to 6 stories high, are considered to be mid-rise buildings, and should follow the commercial section of the City of Austin energy code effective September 16, 2013 [41].

### 4.2.1. Basic requirements

The 2013 Multifamily Rating Basic Requirements for obtaining a one star rating and fulfilling the minimum requirements for all higher ratings are presented below in Table 1 [41].

**Table 1: The measures that are needed to fulfill the basic requirements which are the minimum requirement for all star ratings.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Plans and Specifications</td>
<td>Provide access to the complete set of plans and specifications for review at all major milestones, and at a minimum the 100% Design Development and Building Permit Sets.</td>
</tr>
<tr>
<td>2 Current Codes and Regulations</td>
<td>Meet current City of Austin Codes with local amendments (including energy, building, mechanical, plumbing, electrical, and current drainage and water quality standards applicable for the project site watershed), and applicable building-related laws and regulations.</td>
</tr>
<tr>
<td>3 Transportation Alternatives – Bicycle Use</td>
<td>Provide covered bicycle parking for 15% of residents and permanent building occupants and provide a safe path from property entrance to bike parking. Bicycle spaces shall be racks or lockers anchored so that they cannot be easily removed. Each space allocated for this kind of parking shall be a minimum of two (2) feet wide and six (6) feet long.</td>
</tr>
<tr>
<td></td>
<td>Building Energy Performance</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>Mechanical Systems</td>
</tr>
<tr>
<td>6</td>
<td>Tenant Education</td>
</tr>
<tr>
<td>7</td>
<td>Testing</td>
</tr>
<tr>
<td>8</td>
<td>Indoor Water Use Reduction</td>
</tr>
<tr>
<td>9</td>
<td>Outdoor Water Use Reduction</td>
</tr>
<tr>
<td>10</td>
<td>Low VOC Paints and</td>
</tr>
</tbody>
</table>
Coatings to the building interior must not exceed the VOC limit of Green Seal Environmental Standard GS-11, Edition 3.1, 2013, Section 3.4.

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Filtration for Indoor Air Quality</td>
</tr>
<tr>
<td>12</td>
<td>Storage and Collection of Recyclables</td>
</tr>
<tr>
<td>13</td>
<td>Construction Waste Management</td>
</tr>
</tbody>
</table>

Filtration for Indoor Air Quality
Filters installed in ventilation systems shall have a minimum efficiency reporting value (MERV*) rating of 7 or greater.

Storage and Collection of Recyclables
Comply with the requirements of the Austin Resource Recovery Universal Recycling Ordinance (URO) (Austin Ordinance No. 20130425-007) regardless of size or type of project. Provide appropriately sized, easily-accessible, clearly-marked area(s) dedicated to the collection, separation and storage of the following materials:
- Paper
- Cardboard
- Glass containers
- Aluminum cans
- #1 & #2 plastic containers and bottles.

All projects over 100,000 square feet must also provide safe storage and recycling of batteries and fluorescent lamps.

Construction Waste Management
Recycle and/or salvage at least 50% (by weight) of non-hazardous construction and demolition waste, excluding excavated soil, stone, and land clearing debris. Diverted material must include at least four material streams (i.e. concrete, asphalt, metal, wood, paper and cardboard, plastic).

4.2.2. Star-rating levels
There are 5 star-rating levels [41]. To receive a one star rating the basic requirements, presented in Table 1, has to be fulfilled. However, to receive a higher star rating a number of points are also needed in addition to the basic requirements and these are presented in Section 4.2.3. Fulfilling the basic requirements does not grant the project any points. The points required to achieve a star rating through the 2013 Multifamily Rating program are presented below [41]:

- 1 star Basic requirements
- 2 stars 29-42 points
- 3 stars 43-51 points
- 4 stars 52-66 points
- 5 stars 67 points or more

4.2.3. Additional categories with measures for higher ratings
To receive a higher rating there are a number of categories with different measures that the project can comply with to receive a higher rating. The categories and the total points available for each category are presented in Table 2 [41].

<table>
<thead>
<tr>
<th>Category</th>
<th>Point(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Team</td>
<td>1</td>
</tr>
<tr>
<td>2 Site</td>
<td>20</td>
</tr>
<tr>
<td>3 Energy</td>
<td>26</td>
</tr>
<tr>
<td>4 Water</td>
<td>11</td>
</tr>
<tr>
<td>5 Indoor environmental quality (IEQ)</td>
<td>15</td>
</tr>
<tr>
<td>6 Materials and resources</td>
<td>16</td>
</tr>
<tr>
<td>7 Education and equity</td>
<td>9</td>
</tr>
<tr>
<td>8 Innovation</td>
<td>5</td>
</tr>
<tr>
<td><strong>Grand total points</strong></td>
<td><strong>103</strong></td>
</tr>
</tbody>
</table>

Since the focus of this degree project is on the energy and demand savings, the requirements for the energy measures can be found in Appendix C. The energy category is also the category that contains the most points, 26 out of 103, which represents approximately 25% of the points available to receive a higher star rating [41].

4.3. **How savings are calculated**

As mentioned earlier energy and demand savings can only be estimated since it is impossible to measure energy savings. Therefore there is always a level of uncertainty when estimating the savings. The participating buildings have the option of following a prescriptive approach, where certain measures give a predetermined amount of points [41]. The past 2 years participants have had the option to follow a performance approach and make an energy model for the building [41]. For the prescriptive approach deemed savings are used to estimate projected energy and demand savings and for the performance approach the projected savings are modeled.

4.3.1. **Deemed savings**

To estimate projected savings for the prescriptive approach deemed savings are used. The deemed savings values have been calculated from models of prototypical multifamily buildings in the Austin area by AEGB personnel. For previous years, before
the 2013 Multifamily Guidebook was published, there was one deemed saving value for low-rise multifamily buildings, defined as buildings 2-3 stories. The prototypical building that was modeled was assumed to have 3 stories, see Table 3. The baseline code that was used was the 2009 International Energy Conservation Code (IECC). The other deemed savings value, also valid before the 2013 Multifamily Guidebook, was for mid-rise multifamily buildings defined as buildings 4-6 stories high. The prototypical building that was modeled was assumed to be 5 stories high, and also used the 2009 IECC as baseline code, see Table 3. The reason for the difference between the deemed savings value for low-rise buildings and mid-rise buildings is due to the fact that the baseline models are based on different codes.

Table 3 Prototypical low- and mid-rise building, with respective baseline code and deemed savings factor.

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Baseline code</th>
<th>Deemed savings factor: [kWh/sqft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-rise (3 stories)</td>
<td>2009 IECC Chapter 4</td>
<td>0.47</td>
</tr>
<tr>
<td>Mid-rise (5 stories)</td>
<td>2009 IECC Chapter 5</td>
<td>2.17</td>
</tr>
</tbody>
</table>

Each prototypical building was first modeled for the baseline scenario, where no energy efficiency measures have been carried out. For the baseline model the latest City of Austin energy and building codes are used to decide building features, so the model replicates a building built according to current energy and building codes. Currently, the City of Austin has adopted the 2012 IECC with local amendments. Every time a new energy code is adopted the prototypical building fulfilling all the requirements to meet the code is modeled so that the baseline is always up to date. After the baseline has been modeled the model is changed to meet all the basic requirements to receive a 1 star rating. These requirements are also the minimum needed for all star ratings. After these two scenarios have been modeled the energy savings for each model are divided by the square footage of the prototypical multifamily building. Then the difference between the baseline model’s energy savings per square footage and the basic requirements model’s energy saving per square footage is calculated. This is what is then claimed to be the deemed savings per square footage in rated multifamily buildings in Austin.
These deemed savings values, based on the basic requirements, are used to calculate and estimate the projected savings for all star ratings when the prescriptive approach is chosen by the participant. This is since the basic requirements are required for all star ratings and the higher star ratings are based on how many additional points a project receives. Since the participants chose themselves which additional points to pursue it would be too time-consuming for AEGB to model all possible ways of receiving additional points for the prescriptive approach. An additional concern that makes it complicated is that to get a higher star rating the project does not have to receive more points related to energy measures. A building can thus receive a higher star rating without making the building more energy efficient. AEGB has made the judgment to use the deemed savings value, calculated for a one star rated building, for all buildings that follow the prescriptive approach, regardless of which star rating they receive to estimate the savings from the buildings. AEGB is aware that the projected savings may be underestimated because of this.

4.3.2. Modeled savings

Since 2011, AEGB personnel have started modeling energy savings for buildings going through the prescriptive approach, in house, after the building has been built. For these buildings, the deemed savings value is used to project savings for the project and then after the building has been built, an AEGB personnel models the building and reports claimed savings from the energy model.

For the past two years, multifamily buildings going through the program have had the option of following a performance approach. For this approach the buildings are required to show projected savings at a certain percentage better than a baseline model. The baseline model is built according to the specifications outlined in the IECC Standard Reference Design for buildings complying with the residential energy code or the Performance Rating Method of ASHRAE 90.1 for buildings complying with the commercial energy code. These projects submit an energy model for the baseline and a model of the proposed design with all the energy efficiency measures they are planning to undertake. AEGB approves the use of the following simulation programs:

- Carrier HAP
• Trane Trace
• eQuest, DOE2
• EnergyPlus
• Energy Pro
• IES

AEGB staff evaluates the model and approves it when it meets their standards. The estimated savings are then calculated as the difference between the baseline model and the model for the projected energy usage. This approach has the advantage of reflecting on the projected energy savings if additional energy efficiency measures are implemented in order to receive a higher rating than the one star rating.
5. Review of evaluation guidelines, concepts and approaches

In this degree project a number of different guidelines, protocols and approaches have been studied about how to carry out evaluation of energy efficiency programs. Three of these approaches will be presented in this chapter. Measurement and verification (M&V) is the practice of verifying savings from individual energy efficiency projects. M&V was studied because it is a commonly adopted method for verifying savings. Evaluation, measurement and verification (EM&V) is the practice of verifying savings from energy efficiency programs and portfolios of programs. Searching for research articles on evaluation of green building programs, many of them utilized the practice of post occupancy evaluation (POE). Therefore this practice was studied further since it appeared to be a common method in the research field.

5.1. Measurement and verification

M&V is carried out by measuring the energy use after the measure has been installed and comparing this to a baseline [12]. In the Efficiency Valuation Organization’s (EVO) International Performance Measurement and Verification Protocol (IPMVP) [13] the following general equation for estimating savings is presented:

$$\text{Savings} = (\text{Baseline period energy use or demand} - \text{Reporting energy period use or demand}) \pm \text{Adjustments}$$

M&V is the practice of collecting and measuring data, analyzing it and calculating actual energy and demand savings for specific energy efficiency measures, sites or projects [43]. Two of the protocols that have been studied for M&V are EVO’s IPMVP and ASHRAE’s Guideline 14 – Measurement of Energy and Demand Savings. They both discuss the same principles but EVO’s protocol is broader and less technical while ASHRAE’s guideline goes more in-depth and offers more technical background and theory of the practice [44].
M&V builds upon 6 principles [13]. First, the process should yield as accurate results as possible allowed by the budget [16]. However, a rule of thumb is to not spend more than 10% of the yearly savings on M&V of the project [13]. Secondly, the process should include all aspects of the project to give a complete picture. Third, it is recommended to be conservative, hence underestimated savings are preferred over overestimated savings. Fourth, the reporting should be consistent over time. Fifth, relevant parameters should be metered and less relevant parameters can, if needed, be estimated [16]. Lastly, transparency is recommended and the process should be well documented.

The process of M&V starts with documenting the baseline energy and planning for the M&V activities for the project. When the measures have been installed the operation of the measures has to be verified which can be done through site visits. Reporting data needs to be metered and gathered, the savings need to be verified and then reported [13]. Both IPMVP and ASHRAE’s Guideline 14 present three general approaches to M&V depending on the nature of the project [13, 16]:

1. Retrofit isolation
2. Whole facility
3. Calibrated simulation

Since Austin Energy Green Building (AEGB) is interested in the overall savings from the buildings and not specific measures the focus will be on the whole facility approach and calibrated simulations approach.

5.1.1. Whole facility

The whole facility approach estimates the energy and demand savings from the whole building. This approach can be used where multiple energy efficiency measures have been installed and one does not want to estimate savings for each one. It can also be used when utility billing data is available [13]. Further, the approach can be used when meters are already in place to meter whole facility data or sub metered data for part of the facility. With this approach it is important that the energy savings are a substantial part of the energy use of the building. If utility data is used it is recommended that the energy savings at least constitute 10% of the baseline energy usage if the reporting
period is less than two years [13, 16]. This will help during the analysis of the data to determine if the changes in energy use can be contributed to the energy efficiency measures installed or if it is due to other changes, for example the weather or changes in building use [16]. When energy data is derived from utility bills it will be important to find out what kind of data that is reported. Utility bills may contain estimated data for small accounts which is not always stated on the invoice. If the utility data is estimated it can result in errors in the savings estimates [13, 16].

When using the Whole facility approach independent variables need to be taken into consideration. Weather can affect energy usage of a facility in many ways but for this approach the outdoor dry-bulb temperature will have the largest impact [13]. The occupancy depends on how the building is being used. In multifamily buildings fluctuations can be daily, for example when tenants leave for work. There can also be longer periods of absence, for example if tenants go on vacations or when apartments are not rented out. To analyze the impact these independent variables have on the energy use, data needs to be metered during the reporting period [13]. Using average data or monthly mean data will result in unnecessary errors. Data should be taken for sets of whole years, for example 12, 24, 36 months and so on [16]. Data can be metered hourly, daily or monthly [16] and if the data is metered hourly it should be added together to daily data to make the data management easier [13]. To correlate the independent variables to the baseline period and to determine how many variables to take into consideration mathematical models and regression analysis can be used [13, 16]. The cost of using the Whole facility approach depends on what kind of data is used, if utility data can be utilized or if independent meters will need to be installed [13].

5.1.2. Calibrated simulation
The approach of calibrated simulations is the practice of simulating the energy usage for the reporting period, the baseline period or both [13, 16]. Then the simulation is calibrated with the help of metered data so the energy patterns in the simulation are representable of the actual energy usage [13, 16]. This approach requires personnel that have experience with simulations as well as calibration with the help of metered data [13]. This approach is best utilized when baseline data is missing, for new construction
or when metered data is unavailable from the reporting period. It can also be used for the evaluation of specific energy efficiency measures where it is too difficult or expensive to meter data to use the Retrofit isolation approaches [13]. It is important that key parameters are metered and that as much actual data as possible is used for the simulations. Also it is not enough that total simulated energy use and total actual energy use are the same, it is the patterns of energy usage and demand that are important. Therefore the patterns are what need to be comparable between the simulated energy and demand data and the actual energy and demand data [13, 16]. The simulation work should be documented, which include all the input parameters, the values used and the version and name of the software used to carry out the simulations [13]. It can also be a good idea to have the same person or team simulate the “as-designed” building and the “as-built” building since this will lend more consistency to the project as well as the simulation efforts.

There are a number of simulation programs available and which program that should be used depends on the complexity of the project and simulations [13, 16]. When calibrating the simulation a set of utility data, reported over a year, is usually used. In addition to the utility data, key parameters can be measured and used for calibration [13]. The calibration data should account for energy usage and independent variables such as weather [16]. The calibration of the simulation models is done to make sure that it with some predetermined accuracy predicts the energy patterns of the facility [16].

The Calibrated simulation approach is usually used when it is not possible to use one of the other options. If the savings are of interest during years to come, this approach can be used to establish a baseline and then the Whole facility approach can be used to estimate the savings for the following years. This is usually more cost effective.

**5.2. Evaluation, measurement and verification**

Evaluation, measurement and verification (EM&V) is different from M&V in that EM&V is the practice of evaluating whole programs or portfolios of programs instead of evaluating individual projects and energy efficiency measures [12]. The practice of EM&V builds on three key objectives [12]. The first is to document impacts and benefits to make sure the program lives up to its goals. The second is to understand and improve
program performance with the help of the EM&V effort. The third is to support energy resource planning since evaluation of programs can lead to better adoption and support of energy efficiency programs in the future [12]. One of the documents that has been studied for EM&V is the State & Local Energy Efficiency Action Network’s (SEE Action) Energy Efficiency Program Impact Evaluation Guide, which from now on will be called the Evaluation Guide [12].

There are three different evaluation categories, impact evaluation, process evaluation and market effects evaluation [12]. Impact evaluation evaluates the outcomes of an energy efficiency program and is interested in changes that can be attributed to the program. Some examples are energy and demand savings, avoided emissions of greenhouse gases (GHG) and creation of new jobs. Process evaluation evaluates how the program operates and focuses on finding out where the program operates efficiently and to find key areas where the program can be improved [12]. Market effects evaluation is a way of evaluating how the market changed or how the behavior of market participants changed after the implementation of one or more energy efficiency programs [12]. One example is an incentive program for buying energy efficient appliances. While the program is in place, more people are likely to buy energy efficient appliances since they can receive an incentive when doing so. The market effects evaluation would look at how many people continued to buy energy efficient appliances after the incentive is gone. Did people go back to buying the standard appliances or did people continue buying the energy efficient appliances and thus change the market?

When performing program evaluations there are three different metrics that can be evaluated and these are gross energy and demand savings, net energy savings and non-energy benefits or impact. There are also three approaches to determine the energy and demand savings. These are the deemed savings approach, the M&V approach and the large scale consumption data analysis approach. When choosing an EM&V approach it is important to keep the goals and objectives of the program in mind. There are some criteria that apply for all of the approaches [12]. The evaluator has to be familiar with the practice so that the best possible evaluation can be conducted. There also has to be enough time, data and money [12].
EM&V should be an integral part of all energy efficiency programs and the planning for EM&V should start with the planning of the program. When planning for EM&V of a program the objectives and metrics need to be specified and defined, an evaluation approach need to be selected and relevant data need to be collected [12]. This way it is easier to make sure all data that will be needed for the evaluation can be monitored and documented [12]. During the implementation of the EM&V plan, the verification of the specified metrics will be carried out and determination of specified savings in the plan will be calculated. During the reporting phase the evaluated savings will be reported [12]. The problem with planning for EM&V at a later phase in the program execution is that some necessary data may not have been documented and can then be difficult and sometimes even impossible to retrieve. Thus planning for EM&V from the start will minimize the risk of this happening [12]. Planning for EM&V can start with deciding a framework for the evaluation, which parameters and metrics that are of interest, how the baseline will be defined and establishing who will do what. This will set the tone for the effort and can aid in the coming development of the EM&V plan. In Appendix D an evaluation plan outline and checklist from The Evaluation guide can be found [12].

5.3. Post occupancy evaluation

Post occupancy evaluation (POE) is when the performance of the building is evaluated after the occupants have moved in to the building [25]. POE has two focuses, energy performance of the building and occupancy satisfaction with the building. POE is usually carried out through monitoring of energy data, performing site visits to assure that the energy consuming systems work as efficiently as predicted and by surveying tenants to find out what they think about the building [25]. When evaluating the energy performance the metric used for comparison is often energy use intensity (EUI). EUI is the total energy consumed by a building during a year divided by the gross square footage of the building measured in \([kBtu/sq\ ft/\text{year}]\) [45]. The energy performance can be evaluated in four ways. The first way is to compare the actual energy data, which has been monitored, with the projected energy data [25]. This gives a clue whether the actual energy use is consistent with the projected energy use and if there are any

---

1 Gross square footage is the total area of the building. It is calculated from the exterior walls and includes common areas as well as areas used for maintenance and operations.
peculiarities to look into. If the two are somewhat the same it can be assumed that the baseline used to project savings is also correct and that the projected savings are representative for the building [9]. The second way is to compare the actual energy data with the baseline building code to evaluate actual savings [25]. The accuracy of the baseline depends on if it has been modeled or measured. The third way is to compare the actual energy usage to the energy usage of a representative group that has the same characteristics as the building being evaluated [25]. Two different ways of doing this is to find representative average buildings to compare the building with from the Energy Star Target Finder and/or the Commercial Building Energy Consumption Survey (CBECS) [46]. The fourth way of evaluating the actual energy usage is if the building owner owns other buildings. The energy usage of the buildings can then be compared with each other [25]. Even if no analysis of the uncertainty for the comparison is made, if conducting all of these comparisons it can give a well-rounded basis for the results [25].

To visualize the results for actual compared with projected energy usage, the actual EUI for the building can be plotted against the projected EUI [21]. An example of this is shown in Figure 3 taken from Turner’s study of 121 Leadership in energy and environmental design (LEED) buildings. The black line represents the values where the projected EUI is the same as the actual EUI. With the projected EUI on the x-axis and the actual EUI on the y-axis this will mean that all red dots above the black line represents buildings where the projected EUI is lower than the actual EUI, hence the building perform worse than expected. On the other hand, the red dots below the black line will represent buildings where the actual energy usage was lower than the projected energy usage and hence perform better than expected. This kind of graph makes it easy to see if the majority of buildings perform better or worse than expected [21].
The actual EUI for the 121 LEED buildings range between 20 and 120. The LEED buildings represent different types of buildings which can explain the large range [21]. LEED has 4 ratings, certified, silver, gold and platinum. In the sample Turner looked at there were only 2 buildings out of 121 that had received a platinum rating and therefore the gold and platinum ratings were added together to one group in the study [21]. As can be seen in Figure 4 the measured EUI is fairly scattered for all the different ratings.

Figure 3 Projected EUI plotted against the actual EUI for each building [21].

Figure 4 Actual EUI plotted for three different LEED certification levels, Certified, Silver and Gold-Platinum combined [21].
The median measured EUI is also displayed and for the certified rating it came out to 67.4, for the silver rating 61.7 and for the gold and platinum rating it came out to 51.2. For the study the median measured EUI got lower with a higher rating. Turner used median EUI’s throughout her study as she saw it as more representative than the mean. With scattered values she reasoned that the mean may be skewed by low or high values [9, 24].

When studying program wide savings, dividing the measured actual energy data by the projected energy data, can be useful [21]. This can help evaluating the accuracy of the projected savings. The results can be used by utilities to predict future energy loads and demand and it can also be used when developing new energy policies [21]. When the projected energy data and the actual energy data have the same value, the ratio comes out to 1. This is the desired ratio since this means that the average energy usage over a year correlates for the projected energy usage and the actual energy usage [21]. Figure 5 displays the ratio between the measured actual EUI and the projected EUI for the different rating levels.

![Figure 5 Ratio of actual EUI to projected EUI by LEED certification level](image)

It also shows the median ratio for the different levels. The median for the certified rating level is 0.93, the median for the silver rating level is 0.83 and the median for the gold and platinum rating level is 1.12. If all the rating levels are combined and the median is
taken from the whole sample, the median comes out to 0.92 [21]. So even though the spread is fairly big for the different rating levels as well as the sample as a whole, the medians for the different rating levels as well as the whole sample are fairly close to one. This means that overall, for the whole program, the predictions of the energy usage are good [21]. Looking at individual buildings though, there is little that can be said about the accuracy of the projected energy usage compared to the measured actual energy usage [21].

Turner used the following formulas to calculate the projected savings and the actual savings [21]:

\[
\text{Projected savings} = \frac{\text{Modeled baseline EUI} - \text{Modeled projected EUI}}{\text{Modeled baseline EUI}}
\]  

(7) 

\[
\text{Actual savings} = \frac{\text{Modeled baseline EUI} - \text{Actual EUI}}{\text{Modeled baseline EUI}}
\]  

(8) 

Figure 6, from Turner’s study of 121 LEED buildings, shows savings as a percentage of the baseline for projected savings and measured actual savings [21].

![Figure 6](image_url)

Figure 6 Projected and actual savings as percentage of baseline energy usage [21].
As can be seen in Figure 6 the median values for the savings are almost the same for the projected savings and the measured actual savings, 25 % and 28 % respectively. Also the spread of the measured actual savings is a lot bigger than the spread of the projected savings [21]. The conclusion that can be drawn from this study is that even though the spread is large for the individual projects, the prediction of the overall savings for the program as a whole are fairly good [21].

However, when looking at individual projects, the spread is large and in Figure 7, also from Turner's study, it is displayed how some buildings even use more energy than the predicted baseline. The figure shows which buildings performed better than predicted, which performed worse than predicted and which buildings even performed worse than the code baseline [21].

Figure 7 Measured savings plotted against projected savings where all dots below 0 % on the y-axis shows buildings using more energy than the baseline.

To reduce the spread in the projected savings compared to the measured actual savings, it could be interesting to study the buildings that performed worse than the code baseline further. Figuring out why these buildings performed so much worse than
projected can help 1) in adjusting the operations of the systems in the building to reduce
the energy usage and 2) as lessons learned which can be used for bettering procedures
for future projects and programs.

To perform site visits to make sure the systems in the building are operating as planned
and as efficiently as possible is also an important part of POE [25]. There can be a
number of ways to explain discrepancies between the projected energy usage and the
measured actual energy usage. One can be the use of new and unfamiliar technologies. If
the building architect and designer incorporate new technologies it is important that the
building operator receives training on how to accurately operate them [25].
6. Results and discussion

6.1. Discussion of the different evaluation approaches

M&V and EM&V both build on the premise that the evaluation plan is developed during the initial stages of a project and program. As a result it is assumed that all data that is needed will be metered. Thus it will be available at the evaluation stage of the project or program. AEGB decided to perform an evaluation of buildings that have already been built. However, not all data that is necessary to conform to some of the evaluation guidelines presented previously in the chapter are available.

AEGB are interested in the accuracy of the savings from the program as a whole and not of particular buildings or measures. This chapter will discuss the previously presented approaches and how and why they are or are not applicable for AEGB’s evaluation of the multifamily program.

Since AEGB are interested in the savings from the whole program EM&V or POE are the evaluation approaches that are most relevant. For EM&V there are three ways to carry out the evaluation; M&V, deemed savings and large scale consumption data analysis.

The first approach that is examined is the M&V Whole facility approach. This approach can be used when the energy and demand savings from the whole facility is of interest. This approach requires that data for the baseline period as well as the reporting period is available or can be metered. Since data is needed for the baseline period as well, this approach is meant to be used for energy efficiency retrofit measures and not for new construction. The buildings going through AEGB’s multifamily program has thus far been new constructions. Therefore this approach is not applicable due to the fact that measured data or utility data are not available for the baseline period.

The next approach to be examined is the M&V approach of Calibrated simulation. This approach can be used when the energy usage for the baseline period, the reporting period or both needs to be simulated. This requires personnel with expertise in energy simulations. This approach is applicable for new construction where data for the baseline period is nonexistent. Therefore this approach can potentially be used by AEGB to evaluate the savings from their multifamily program. When using this approach the
Simulations have to be calibrated with the help of metered data so the simulations are representative of the actual energy use and demand patterns [13]. Since AEGB has been using deemed savings to project energy and demand savings for the majority of the buildings, no individual energy models are available for these buildings. The past two years, participating building owners have had the possibility of choosing the performance approach. One of the requirements for the performance approach is to model the energy and demand savings for the building. Since AEGB does not get the actual model but the input parameters and the results from the model they will not be able to calibrate the model with metered data. Therefore there is no way of carrying out this approach as of today for AEGB's multifamily program. Therefore AEGB will not be able to use the M&V approaches in this evaluation effort. However, this approach may be used for future evaluation efforts if more buildings start to use the performance approach.

While one of the principles of M&V is conservativeness [13], EM&V upholds the approach of neither overestimating nor underestimating savings [12]. The evaluation guide recommends always striving for reporting as real and correct values as possible of the estimated savings and says that underestimating savings can be just as misleading as overestimating savings [12].

AEGB wants to evaluate their deemed savings value. Therefore the projected energy savings based on the deemed savings value will be compared to existing utility data to decide if today's deemed savings value is representative of the actual energy and demand savings from the multifamily building program. However, since the deemed savings calculation values is what needs to be evaluated the deemed savings evaluation approach cannot be used to estimate the evaluated savings.

The third approach for EM&V is large scale consumption data analysis. This approach is meant to be used for large populations. However, currently the population of buildings in the multifamily program is small. The approach is recommended for populations of more than 100 participants [12]. Looking at all the buildings from the start of the program, there are 101 buildings that has gone through the multifamily rating program. However, AEGB knows that some of the past models for the deemed savings value are
not as accurate as they would have liked them to be. Therefore the focus will be on the 39 buildings that have come through the program since the beginning of 2008 and this approach will not be recommended for the evaluation effort that is to be performed by AEGB during the fall. In the future, when more buildings have gone through the program, this approach may be applicable if AEGB can find representative buildings that can function as the control group.

The data that is available to AEGB for this evaluation are the projected energy savings and utility data. With this data the POE approach can be used. Earlier studies that have utilized POE that were shown in the previous section used EUI as metric. This can make it easier to evaluate a larger number of data points. The EUI for the buildings in the multifamily program can be calculated by dividing the energy usage from a year of utility bills by the square footage of the building. One drawback with using EUI as the evaluation metric is that it disregards the patterns of energy use, since it is an average for the whole year. However, since AEGB uses a deemed savings value to project the savings for the majority of the buildings going through the program, the projected savings are also averages. Using this approach AEGB can choose to evaluate the whole population of buildings or a sample.

By using EUI as metric AEGB may compare the EUI for projected energy use from the deemed savings calculations and compare this with the actual EUI of the building as can be seen in Figure 3 in Section 5.3. The EUI’s can also be plotted against their star rating to see if the rating has an influence on the energy use of the building, an example of this is shown in Figure 4 in Section 5.3. The reason why AEGB’s data has not been plotted is because the utility data (actual data) was not available at the time of this degree project.

A way of combining data analysis and POE would be to use the approach of comparing the utility data from the buildings participating in the program with buildings with similar characteristics. In the studied POE reports two different approaches were used to do this. Buildings in the programs were compared with buildings from CBECs and with average buildings from the Energy Star portfolio. Since AEGB’s multifamily program only has participants in Austin they may collaborate with the City of Austin to find a representative group for the comparison. They could look at building permits to
find buildings with similar characteristics that were built according to the desired building code. Utility data could be retrieved for these buildings and this group could be used as the control group and baseline. Then utility data from the buildings built to code could be plotted with the utility data from the buildings participating in the multifamily rating program. Assuming that the building built to code is acting like the baseline for the building participating in the program the savings would be represented by the difference between the two groups. It would look similar to Figure 2 in Section 3.6. The blue line would represent the energy use of the building participating in the program and the green line would represent the energy use of the building built to code. Since it would be possible to retrieve utility data for all building pairs for the same time period, no adjustment for weather conditions would be necessary.

A way of evaluating the savings from more buildings on a regular basis could be to incorporate M&V of projects into the multifamily rating program. It could be added as one of the additional categories for which projects can receive points to get a higher star rating. As more projects choose to go through the program with the performance approach, M&V could be done with the calibrated simulation approach. Performing M&V is something that the building owners also could gain from. This will let them know if their buildings perform as they hoped. And if it is not operating or performing as expected they have a chance to correct the issues. One measure to receive extra points could be to comply with ASHRAE’s Guideline 14 for performance approaches. The maximum level of uncertainty allowed is 50% of the annual energy savings with a 68% confidence level on a per-project basis[16].

In the future as evaluation of energy efficiency measures become more common it may be possible to make M&V one of the basic requirements for all buildings using the performance approach. Today it may discourage project managers from using the performance approach, since they would need to have personnel who are familiar with the calibrated simulations approach on the team. But as M&V becomes a more common practice and more modeling engineers become familiar with calibrating simulations with metered data it may be feasible.
The flowchart in Figure 8 may be used to decide which evaluation approach is best suited for a certain study. It contains an overview of the topics discussed above and can help visualize how and why a certain evaluation approach may or may not be chosen.

Figure 8 Flowchart for how a suitable evaluation approach may be chosen.
6.2. Criteria for inclusion

When analyzing data it is important to decide what kind of data that should be included. One can choose to look at all data but this may not always be the best approach. In this chapter, some criteria for inclusion will be established for the buildings going through the multifamily rating program. Further, the projected data from these buildings has been analyzed in Section 6.3.

To date there has been 39 buildings rated in AEGB’s multifamily rating program from the start of fiscal year 2009, which started October 1st 2008. A decision was made to not include buildings from the program’s earlier years because AEGB changed their method for calculating deemed savings in 2008. The only other criterion for inclusion is that the buildings need to have a full year of energy use data to be evaluated. This criterion was chosen because a number of post occupancy evaluation (POE) studies were found where this was the criterion for inclusion[9, 25, 45]. This excludes 9 buildings from the years of 2013 and 2014 which leaves 30 eligible buildings. There was also one building that no energy savings were accounted for. Perhaps an error occurred when transferring the data, however this building will also be excluded from the population. The 29 buildings left, which will constitute the population, are presented and sorted by star rating in Table 4.

Table 4 Number of buildings sorted by star rating.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Number of buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29</td>
</tr>
</tbody>
</table>

However, Danielski found that the time elapsed from when the building was built until the time of evaluation of the energy performance was the most significant variable for the evaluation. He found large variations in the energy use when buildings were evaluated earlier than two years after they were built [32]. Furthermore, Newsham et. al. pointed out the problems that can occur during the first years of operation. For example, irregular and unusual energy use may be unavoidable during the initial
operation of the building [11]. If the actual EUI turns out to be large compared to the projected EUI of the buildings when the criterion of one year of full energy use data is used, AEGB may consider studying a few buildings that were built more than two years ago and see if there is any significant difference.

6.3. Analysis of Austin Energy Green Building’s data

AEGB gathers data from all buildings that go through the multifamily rating program. For each building they gather general information as well as data about the energy and demand savings. The general data consists of name of the apartment complex, month and year the building was finalized, number of units in the building, star rating and building use. For example, some of the buildings use the ground floor as office and retail space. The energy data that is gathered consist of projected energy and demand savings for all buildings as well as EUI for some of the newer buildings. To protect the identity of the buildings a simple analysis of the projected energy savings data was made and the result is presented below in Table 5 organized by the date the savings were reported to AEGB.

Table 5 Data for the 29 buildings that have gone through the AEGB multifamily program from start of fiscal year 2009 until January 2013.

<table>
<thead>
<tr>
<th>Projected savings reported date</th>
<th>Star rating</th>
<th>Number of units</th>
<th>Size [sqft]</th>
<th>Projected energy savings [kWh]</th>
<th>Projected energy savings [kWh/unit]</th>
<th>Projected energy savings [kWh/sqft]</th>
<th>Projected power savings [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov-08</td>
<td>2</td>
<td>208</td>
<td>179,560</td>
<td>83,495</td>
<td>401</td>
<td>0.46</td>
<td>61</td>
</tr>
<tr>
<td>Nov-08</td>
<td>2</td>
<td>192</td>
<td>230,000</td>
<td>106,950</td>
<td>557</td>
<td>0.47</td>
<td>119</td>
</tr>
<tr>
<td>Nov-08</td>
<td>2</td>
<td>426</td>
<td>374,480</td>
<td>176,518</td>
<td>414</td>
<td>0.47</td>
<td>129</td>
</tr>
<tr>
<td>Nov-08</td>
<td>3</td>
<td>244</td>
<td>225,888</td>
<td>106,897</td>
<td>438</td>
<td>0.47</td>
<td>78</td>
</tr>
<tr>
<td>May-09</td>
<td>3</td>
<td>26</td>
<td>36,550</td>
<td>17,444</td>
<td>671</td>
<td>0.48</td>
<td>13</td>
</tr>
<tr>
<td>May-09</td>
<td>3</td>
<td>305</td>
<td>494,931</td>
<td>986,620</td>
<td>3,235</td>
<td>1.99</td>
<td>239</td>
</tr>
<tr>
<td>Aug-09</td>
<td>3</td>
<td>62</td>
<td>53,981</td>
<td>25,101</td>
<td>405</td>
<td>0.46</td>
<td>18</td>
</tr>
<tr>
<td>Sep-09</td>
<td>3</td>
<td>258</td>
<td>410,90</td>
<td>191,069</td>
<td>741</td>
<td>0.47</td>
<td>140</td>
</tr>
<tr>
<td>Nov-09</td>
<td>3</td>
<td>335</td>
<td>515,978</td>
<td>239,930</td>
<td>716</td>
<td>0.47</td>
<td>176</td>
</tr>
<tr>
<td>Dec-09</td>
<td>3</td>
<td>269</td>
<td>645,000</td>
<td>299,925</td>
<td>1,115</td>
<td>0.47</td>
<td>220</td>
</tr>
<tr>
<td>Feb-10</td>
<td>2</td>
<td>24</td>
<td>38,500</td>
<td>25,822</td>
<td>1,076</td>
<td>0.67</td>
<td>8</td>
</tr>
<tr>
<td>Jun-10</td>
<td>3</td>
<td>15</td>
<td>13,879</td>
<td>6,453</td>
<td>430</td>
<td>0.46</td>
<td>5</td>
</tr>
<tr>
<td>Jul-10</td>
<td>5</td>
<td>18</td>
<td>35,828</td>
<td>16,620</td>
<td>923</td>
<td>0.46</td>
<td>12</td>
</tr>
<tr>
<td>Sep-10</td>
<td>4</td>
<td>22</td>
<td>15,582</td>
<td>9,988</td>
<td>454</td>
<td>0.64</td>
<td>3</td>
</tr>
<tr>
<td>Mar-11</td>
<td>3</td>
<td>36</td>
<td>39,986</td>
<td>19,000</td>
<td>528</td>
<td>0.48</td>
<td>14</td>
</tr>
<tr>
<td>Apr-11</td>
<td>3</td>
<td>64</td>
<td>27,434</td>
<td>30,891</td>
<td>483</td>
<td>1.13</td>
<td>9</td>
</tr>
<tr>
<td>May-11</td>
<td>2</td>
<td>240</td>
<td>272,971</td>
<td>89,801</td>
<td>374</td>
<td>0.33</td>
<td>38</td>
</tr>
</tbody>
</table>
As can be seen in Table 5, 13 out of the 29 buildings have an energy saving of approximately 0.47 kWh/sqft, which is the deemed savings factor for low-rise buildings (2-3 stories) presented by AEGB. As also can be seen most of the energy savings for the buildings until 2011 were projected with the help of the deemed savings value. After the turn of 2011 the energy savings varies more on a per project basis, because the energy savings are now modeled for the as built building by AEGB personnel. 1 building, from January 2013, has an energy saving of 2.17 kWh/sqft, which is the deemed savings value used to calculate savings for mid-rise buildings (4-6 stories).

3 of the buildings followed the performance path, that is, they created an energy model for the building to calculate the projected savings instead of using the deemed savings value. The energy savings for the buildings following the performance path was 4.93 kWh/sqft, 2.12 kWh/sqft and 2.14 kWh/sqft. These 3 buildings are marked by bold text in Table 5. The energy savings from the two modeled buildings with energy savings of 2.12 kWh/sqft and 2.14 kWh/sqft is close to the deemed savings value for a mid-rise building (4-6 stories). The building with an energy savings value of 2.12 kWh/sqft is a mid-rise building but the other building with an energy savings value of 2.14 kWh/sqft is a low-rise building. This shows that the low-rise building is contributing with larger energy savings than expected. The third modeled building is a mid-rise building that received a 2 star rating and has a considerably larger energy savings value with 4.93 kWh/sqft. This results shows that the energy saving will be
underestimated, especially for higher star ratings, when a deemed saving approach is used instead of the performance approach.

The data for the buildings sorted by star rating can be seen in Table 6. 9 buildings received a 1 star rating and the same number of buildings received a 3 star rating. 6 buildings received a 2 star rating, 3 buildings a 4 star rating and 2 buildings a 5 star rating, see Table 6. This means that a majority, 83 %, of the buildings going through the program from beginning of fiscal year 2009 to January 2013, received a star rating from 1 to 3. These buildings, with a 1-3 star rating, also account for about 4,960 MWh or 96 % of the projected energy savings. Furthermore they account for 92 % of the units and 94 % of the total square footage.

Table 6 Data for the 29 buildings sorted by star rating.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Number of buildings</th>
<th>Projected energy savings [kWh]</th>
<th>Projected demand savings [kW]</th>
<th>Number of units</th>
<th>Total area [sqft]</th>
<th>Area per unit [sqft/unit]</th>
<th>Savings per square foot [kWh/sqft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>1,415,076</td>
<td>387</td>
<td>1,050</td>
<td>1,102,439</td>
<td>1,050</td>
<td>1.28</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>1,646,606</td>
<td>421</td>
<td>1,291</td>
<td>1,331,622</td>
<td>1,031</td>
<td>1.24</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>1,898,229</td>
<td>894</td>
<td>1,552</td>
<td>2,410,546</td>
<td>1,553</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>44,212</td>
<td>17</td>
<td>167</td>
<td>83,894</td>
<td>502</td>
<td>0.53</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>142,620</td>
<td>39</td>
<td>166</td>
<td>207,962</td>
<td>1,253</td>
<td>0.69</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29</td>
<td>5,146,743</td>
<td>1,758</td>
<td>4,226</td>
<td>5,136,463</td>
<td>1,215</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Looking at savings per square footage, the savings seems to be larger for the lower star ratings, especially 1 and 2. The savings average is 1.28 kWh/sqft for the 1 star rated buildings and 1.24 kWh/sqft for the 2 star rated buildings. The higher star ratings show savings from 0.53 kWh/sqft to 0.79 kWh/sqft, which is comparatively lower.

Two of the buildings that received a 1 star rating went with the performance approach and have modeled the savings instead of using the deemed savings value. This may also explain the higher average energy savings per square foot for this group. That the 2 star rating group has such a large savings value per square foot is probably also because of the third building that followed the performance path. It has a modeled projected energy savings value of 4.93 kWh/sqft.
To get another view of the data the buildings were divided up by square footage, as can be seen in Table 7. The majority of the buildings can be found in the first two groups, 0 – 100 thousand square feet and 100 – 200 thousand square feet. 45% of the buildings have a floor area of 0 – 100 thousand square feet and 21% have a floor area of 100 – 200 thousand square feet. 13 buildings out of 29 can be found in the first group, 0 – 100 thousand square feet, however together the buildings account for just below 5% of the projected energy savings. So even though this group contains the largest number of buildings, the energy savings are small in comparison to the other groups.

Table 7 Data for the 29 buildings sorted by area of the building.

<table>
<thead>
<tr>
<th>Area [thousands of sqft]</th>
<th>Number of buildings</th>
<th>Projected energy savings [kWh]</th>
<th>Projected demand savings [kW]</th>
<th>Number of units</th>
<th>Total area [sqft]</th>
<th>Area per unit [sqft/unit]</th>
<th>Savings per square foot [kWh/sqft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>13</td>
<td>249,103</td>
<td>112</td>
<td>454</td>
<td>401,571</td>
<td>885</td>
<td>0.62</td>
</tr>
<tr>
<td>100-200</td>
<td>6</td>
<td>1,404,092</td>
<td>384</td>
<td>1013</td>
<td>978,633</td>
<td>966</td>
<td>1.43</td>
</tr>
<tr>
<td>200-300</td>
<td>4</td>
<td>1,467,668</td>
<td>301</td>
<td>877</td>
<td>964,970</td>
<td>1,100</td>
<td>1.52</td>
</tr>
<tr>
<td>300-400</td>
<td>2</td>
<td>308,336</td>
<td>185</td>
<td>715</td>
<td>724,480</td>
<td>1,013</td>
<td>0.43</td>
</tr>
<tr>
<td>400-500</td>
<td>2</td>
<td>1,177,689</td>
<td>379</td>
<td>563</td>
<td>905,831</td>
<td>1,609</td>
<td>1.30</td>
</tr>
<tr>
<td>&gt; 500</td>
<td>2</td>
<td>539,855</td>
<td>396</td>
<td>604</td>
<td>1,160,978</td>
<td>1,922</td>
<td>0.47</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29</td>
<td>5,146,743</td>
<td>1,758</td>
<td>4,226</td>
<td>5,136,463</td>
<td>1,215</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Looking at Table 7 there does not seem to be any correlation between the different groups of square footage and their respective energy savings per square foot. The group of buildings with an area of 100 – 200 thousand square feet contains one mid-rise building and two of the buildings which had an energy model made. This resulted in an average energy savings value of 1.43 kWh/sqft. For the 4 buildings with an area of 200 – 300 thousand square feet, 3 buildings are low-rise buildings (2-3 stories) but the average savings value is 1.52 kWh/sqft. This may be because the building that has a modeled energy savings value of 4.93 kWh/sqft can be found in this group.
6.4. How a sample of buildings can be selected

As discussed in Chapter 3, it is almost never cost effective to evaluate the whole population of buildings in a program. Therefore a sample has to be chosen. There are numerous ways to go about this task and in this chapter the most suitable options will be presented followed by a short discussion of which one should be recommended for this particular program.

6.4.1. Option 1: Simple random sample

One statistically accepted approach is to use a simple random sample. This means that out of the whole population a random sample would be selected regardless of rating or if the building used the prescriptive approach or performance approach to receive a star rating. This is an unbiased approach and all buildings have the same chances of being chosen to be a part of the sample. To get an idea of how many buildings should be evaluated, an initial sample size will be calculated with the help of equation (1) and (2) in Section 4.5.1. The sample size will be calculated for two common confidence and precision requirements. According to the Uniform Methods Project (UMP), the confidence level is most commonly set at 90% and with a relative precision of 10 % for energy efficiency evaluations [36][37]. Therefore, these values will be used for the first calculations. For an infinite sample size with a 90 % confidence level the z-value is 1.64 [13]. The coefficient of variance will be assumed to be 0.5[13][36].

Thus the initial sample size with the desired confidence level and precision is 68. The problem is that the population being evaluated only consists of 29 buildings. To account for the small population the initial sample size will need to be adjusted with the Finite Population Correction (FPC) and rounding up to the nearest integer the sample size is then calculated to be 21. A sample of 21 from a population of 29 is a substantial fraction of the population. This may show to be an expensive endeavor. Since the evaluation effort always needs to be weighed against the expense of the evaluation, a sample size for a less restrictive requirement will be calculated. Another commonly used criterion is a confidence level of 90 % and 20 % relative precision [36][37]. This leaves the z-value of 1.64 and the coefficient of variance is still assumed to be 0.5. For this confidence level
and precision the initial sample size is calculated to 17 and adjusting for the FPC the sample size is calculated to be 11.

6.4.2. **Option 2: Stratified random sample**

When evaluating a heterogeneous sample, like in this project, a stratified random sample can be preferred over a simple random sample [36]. This will ensure that all different categories of the population are represented in the final sample. Stratified random sample also helps minimize the variation in the strata and hence the variation for the whole sample [36]. When choosing strata it is important to choose categories that are representative for the population and for the specific study. For this study two possible ways of categorizing the population have been chosen. By star rating as can be seen in Table 6 and depending on the size of the buildings as can be seen in Table 7. A sample will be calculated for each one of these categories for the two different sample sizes.

**Stratified random sample by star rating**

First the overall sample size needs to be determined and for a confidence level of 90 % and a relative precision of 10 % the sample size was determined to be 18 with equation (3). Further samples for each star rating were calculated, with equation (4), proportional to the projected energy savings. The percentage of projected energy savings for each strata is presented together with the sample sizes in Table 8. After rounding the values up to the nearest integer, this would give a final sample size of 20 buildings divided up among the different star ratings. For the 2 star rated group the strata sample size is the same as the population size for the strata. The final sample size of 20 buildings results in a slightly bigger sample than the initial sample size of 18 buildings.

A stratified sample was also calculated for the 90 % confidence level and 20 % relative precision requirement. For this requirement the total sample size was calculated to 10 buildings with equation (3). The same strata sample size calculations were carried out for this requirement and the result are also presented in Table 8. After rounding the values up to the nearest integer, this would amount to a final sample size of 13 buildings, slightly bigger than the initial sample size of 10 buildings.
Table 8 Sample size for the 90/10 and 90/20 criterion for buildings where the projected savings are sorted according to star rating assuming the variation is proportional to the savings of each strata.

<table>
<thead>
<tr>
<th>Star rating</th>
<th>Percent of projected savings</th>
<th>Number of buildings</th>
<th>Strata sample size 90/10</th>
<th>Sample size 90/10</th>
<th>Strata sample size 90/20</th>
<th>Sample size 90/20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.49%</td>
<td>9</td>
<td>4.93</td>
<td>5</td>
<td>2.75</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>31.99%</td>
<td>6</td>
<td>5.74</td>
<td>6</td>
<td>3.20</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>36.88%</td>
<td>9</td>
<td>6.61</td>
<td>7</td>
<td>3.68</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>0.86%</td>
<td>3</td>
<td>0.15</td>
<td>1</td>
<td>0.09</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>2.77%</td>
<td>2</td>
<td>0.50</td>
<td>1</td>
<td>0.28</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>29</td>
<td>20</td>
<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stratified random sample by size of building

Besides sorting the buildings by star rating they can be sorted by building size. The buildings were divided into strata by 100 thousand square feet, which are presented in Table 9. For the 10% precision with a 90% confidence level the sample size was calculated, following the same procedure as above, and once again assuming that the variation is proportional to the savings. The sample size was calculated to 13 buildings with equation (3). The results of the strata sample calculations are presented in Table 9. For the 90/10 requirement rounding up to the nearest integer the sample size would result in 15 buildings. However the final sample size is restricted in size by how many buildings there are in each stratum. Since the variation is assumed to be proportional to the savings in each stratum and not to the number of buildings the first stratum, 0 – 100 thousand square feet, sample size will only consist of 1 building, even though the stratum population is 13 buildings. The strata for buildings sized 400 – 500 thousand square feet, the strata sample size is restricted by the population sample size. This results in a smaller final sample size than was originally calculated for each strata and the final sample size is 14 buildings.

Again, the same calculations will be carried out for a confidence level of 90% and a relative precision of 20%. The results of the calculations are presented in Table 9. Rounding up to the nearest integer the sample size calculated by equation (3) would result in 8 buildings. For this requirement, none of the strata sample sizes are restricted
by the number of buildings in the strata population. Therefore the final sample size is 11 buildings which is bigger than the initial 8 buildings.

Table 9 Sample size for the 90/10 and 90/20 criterion for buildings sorted by size of the buildings.

<table>
<thead>
<tr>
<th>Square footage [thousand sqft]</th>
<th>Percent of projected savings</th>
<th>Number of buildings</th>
<th>Strata sample size 90/10</th>
<th>Sample size 90/10</th>
<th>Strata sample size 90/20</th>
<th>Sample size 90/20</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>4.84%</td>
<td>13</td>
<td>0.60</td>
<td>1</td>
<td>0.39</td>
<td>1</td>
</tr>
<tr>
<td>100-200</td>
<td>27.28%</td>
<td>6</td>
<td>3.36</td>
<td>4</td>
<td>2.17</td>
<td>3</td>
</tr>
<tr>
<td>200-300</td>
<td>28.52%</td>
<td>4</td>
<td>3.51</td>
<td>4</td>
<td>2.27</td>
<td>3</td>
</tr>
<tr>
<td>300-400</td>
<td>5.99%</td>
<td>2</td>
<td>0.74</td>
<td>1</td>
<td>0.48</td>
<td>1</td>
</tr>
<tr>
<td>400-500</td>
<td>22.88%</td>
<td>2</td>
<td>2.82</td>
<td>2</td>
<td>1.82</td>
<td>2</td>
</tr>
<tr>
<td>&gt;500</td>
<td>10.49%</td>
<td>2</td>
<td>1.29</td>
<td>2</td>
<td>0.84</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>29</td>
<td>14</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.4.3. Recommendations and future sample sizes

For all stratified random sample sizes that have been calculated all strata are represented. Since the population is relatively small a stratified random sample is recommended for this study instead of a simple random sample. This will certify that all strata are represented in the final sample size. Using a simple random sample on such a small population could result in certain groups being completely excluded from the final sample. Whether to use a stratified random sample based on star rating or by building size will be left to AEGB to decide. However, evaluating savings by star rating would give insight to whether the savings are underestimated for the higher star ratings.

For future evaluations an Excel spreadsheet that automatically calculates sample sizes was prepared, see Appendix E. The calculations takes the criteria for inclusion into account and the required input data is the date for when savings were reported, star rating, total number of units, square footage, projected energy savings and projected demand savings. AEGB can choose the precision, confidence level and coefficient of variance. The spreadsheet then calculates a simple random sample and a stratified random sample for the chosen parameters. The stratified random sample uses the star ratings as strata. The spreadsheet can be used for an unlimited number of buildings and comes with a user manual, see Appendix E.
6.5. Accounting for occupancy

AEGB assumed that all apartments were occupied when calculating the projected savings for the buildings going through the program. During the reporting period the apartment building may not have full occupancy. Therefore vacant apartments could lead to lower actual energy savings than the reported energy savings. AEGB wants to know how correct their current deemed savings value is and including vacant apartments in the evaluation may not give a fair picture of the value.

The market survey for apartment occupancy in Austin made by Capitol Market Research may be used to estimate how many apartments have been vacant. Since AEGB will use utility data from the past year, it will be assumed that the occupancy rates for 2013 presented by Capitol Market Research are representative for the apartments that has gone through the multifamily rating program. The average overall occupancy rate for 2013 was 97.10% and the average occupancy rate for stabilized new construction was 96% during 2013 [30]. These two occupancy rates are probably most representative of the buildings that have been selected for this study, since AEGB will use utility data from 2013. Assuming that the average occupancy rates correspond to how many units were vacant during this time, the energy savings that were lost due to the vacant apartments can be calculated. This in turn corresponds to about $149.3 \text{ MWh}$ and $205.9 \text{ MWh}$ respectively, in lost projected energy savings for the buildings that have gone through AEGB’s multifamily program. The group with newer buildings but where the occupancy has had time to stabilize is most likely the group that AEGB’s multifamily program can be contributed to. The occupancy rate for new construction is likely avoided by the criteria that all buildings going through AEGB’s multifamily program need a full year of utility data to be evaluated. The averages for the occupancy rates may be used to account for vacant units and their influence on the energy savings. This would be a less expensive and time consuming approach then the “occupied unit-days” approach proposed by Tonn et. al [26].

6.6. Uncertainty analysis

When presenting results it is important to account for the accuracy of the results. An uncertainty analysis can be done to quantify the uncertainty of the results of the study.
Selecting a desired precision and confidence level will create an interval around the estimate of the true savings where the true value of the savings can be found with some level of confidence [36]. For energy efficiency evaluations a common desired confidence level is 90%. On a sector or portfolio level the desired precision is commonly set to 10% with a 90% confidence level [36]. On a program level a precision of 20% with a 90% confidence level seems to be common as well [36]. These values are just commonly used values and can vary. It is important that the evaluator makes a decision about precision and confidence requirements that will meet the needs of the specific program being evaluated. These requirements need to be weighed against the effort and budget that has been determined for the evaluation since higher levels of certainty comes with a need of larger sample sizes and overall more extensive evaluations.

To comply with ASHRAE's guideline 14 “Measurement of Energy and Demand Savings” one can follow either a prescriptive path or a performance path. ASHRAE’s guideline 14 is a guideline for M&V for individual projects. If savings are evaluated for a facility that has followed the prescriptive path, no uncertainty analysis is required to comply with the guideline [16]. However, if the building being evaluated used the performance path the maximum uncertainty allowed to comply with the guideline is 50% of the annual projected savings with a 68% confidence level [16]. As more buildings going through AEGB’s multifamily program this is something to take into consideration for future evaluations. This is however the uncertainty on a per-project basis and not for the whole program.
7. Conclusions

Energy efficiency will become more important with higher energy prices. For Austin it is important since the city is trying to save 800 MW to avoid the need of a new power plant. As the field continues to grow evaluation efforts will be important for the field to keep its credibility. This in turn can help in the process of gaining more interest from the general public, companies and investors. To attract people who do not have sustainability as their first priority evaluation of energy efficiency projects will become an important tool to show the benefits from the practice.

The purpose of this degree project was to develop a plan for evaluation, measurement and verification for Austin Energy Green Building’s (AEGB) multifamily rating program. The main goals were to determine criteria for inclusion of buildings to be evaluated, establish a sampling protocol, investigate how to account for vacant apartments during the reporting period and investigate which type of evaluation that was feasible for the program.

It was found that the most commonly used criterion for inclusion for similar studies of LEED certified buildings has been to have at least one year of energy use data [9, 25, 45]. Therefore this is also the criterion that was used to determine the population of multifamily buildings that have gone through AEGB’s multifamily rating program.

A stratified random sample is recommended for this population of buildings since the population is heterogeneous. The buildings range from 10,500 square feet to 645,000 square feet in size and they also have different star ratings from 1 to 5 stars. Since buildings are continuously going through the program and receiving star ratings an Excel spreadsheet that automatically calculates the sample size based on certain criteria was prepared, see Appendix E. Buildings with less than one full year of energy use data will be eliminated and AEGB needs to choose a confidence level, relative precision and coefficient of variance for the calculations. This way AEGB can use the spreadsheet for future evaluation efforts.

Since AEGB assumed all apartments to be fully occupied when determining the deemed savings value, vacant units need to be taken into consideration when evaluating the
savings. Several different methods to account for vacant apartment units were found. Rental occupancy rates were found for Austin and these are probably the most representative values for the buildings going through the multifamily rating program. Since the criteria of at least one year energy use data was used the occupancy rate for newly constructed buildings where the occupancy had had time to stabilize is probably the best value to use. In 2013 this gave a vacancy rate of 4 % which would mean that $205.9 \, MW h$ of projected savings may not be counted for.

Different evaluation approaches and their transferability to AEGB’s multifamily program were studied. Many of the guidelines assume that the evaluation plan is made in the initial state of the project and hence it can be determined which data to meter. This way it is possible to make sure that all data needed for the evaluation is be available at the time of the evaluation. Limited data was available at the time of this degree project. The projected energy and demand savings were available but AEGB are still working on retrieving the utility data from Austin Energy to be able to compare the projected savings with the actual energy savings. Hence, the data available for AEGB for this evaluation will be the projected energy data based on the deemed savings value and the energy models performed by AEGB in-house. AEGB will also receive utility data for the buildings from Austin Energy. Therefore post occupancy evaluation (POE) will probably be the best way to evaluate the savings. However this will not give any feedback of the energy usage patterns during the year. But it will give feedback on whether the deemed savings value is representable for the buildings or not and it will also be a way of getting feedback on whether the projected savings from the higher star ratings are underestimated.

The most difficult part of this project was to find information on whole program evaluation for evaluation of multiple facilities. There are a lot of guidelines for how to carry out M&V of energy efficiency projects limited to single facilities or stand-alone measures. The State & Local Energy Efficiency Action Network’s (SEE Action) Energy Efficiency Program Impact Evaluation Guide provided a good overview and insight to the terminology that may be used. But there is still a lot of room for programs across the country to develop evaluation approaches that suit their particular program.
One of the most important issues for energy efficient buildings in the future will probably be education of the people living in the buildings and building operators. Occupancy and occupant behavior plays a substantial role in how and how much energy is being used in a building. To be able to project the energy usage of a building accurately the building and its systems need to be used as intended.
Bibliography


[40] “Austin Energy Company Profile,” 19-Sep-2013. [Online]. Available: http://austinenergy.com/wps/portal/ae/about/company-profile/!ut/p/a1/jZDBC0jAEIfaqxs7rVnSbbMwM5Immu0LDY1dJV1VXr7lPAQaDm3ge_in38QRQGiPKyTKJRJzsOo2-niCtAOxOwbS2xACQy147uH2cmmLpAPOqNGhsAvH5ta7_eAu3U3YPuuTizHBKsF puWPB_zxz4h-lWmXfIDivsJJQM_aUaEqGAPjphQk9E-N5ayWCmgQNMoaliVMuGMMxG91HueKTDkxKpUTDEoyLzvACEelofyBvgJ90 M/dl5/d5/L2dJQSEvUUt3QS80SmlFL102XzAyODJlQzAySUc3MjgwQUdDQks1 Vk4xOUgw/. [Accessed: 20-Aug-2014].


Appendix A - Statistical parameters

Since energy efficiency programs mostly use population samples, the parameters will be presented for such a sample [12].

First to be calculated is the sample mean, $\bar{Y}$. The sample mean is calculated by adding the values of all individual data points together and then dividing it by the total number of data points [13]:

$$\bar{Y} = \frac{\sum Y_i}{n} \tag{I}$$

Where:

- $Y_i$ is the value of the individual data points
- $n$ is the total number of data points

The sample variance, $S^2$, is the term that decides how much the measured values differ from each other [13]. When the variance is high, the uncertainty of the sample mean is large. To avoid negative and positive variances from cancelling each other out the difference between the values of the data points and the mean are squared [13]:

$$S^2 = \frac{\sum(Y_i - \bar{Y})^2}{n - 1} \tag{II}$$

Sample standard deviation, $s$, is the square root of the sample variance [13]:

$$s = \sqrt{S^2} \tag{III}$$

Sample standard error, $SE$, is used to estimate the precision of the sample mean. Sometimes it is also called “the sample standard deviation of the mean” [13]:

$$SE = \frac{s}{\sqrt{n}} \tag{IV}$$
Sometimes the properties of the total are of more interest than the mean of the sample. The sample standard deviation of the total, \( s_{tot} \), can be used to estimate the precision of the sample total [13]:

\[
s_{tot} = \sqrt{n} \cdot s
\]  

(V)

Coefficient of variation, \( cv \), is the sample standard deviation expressed as a percentage of the mean [13]:

\[
cv = \frac{s}{\bar{Y}}
\]  

(VI)

Absolute precision is calculated with the help of the sample standard error and a \( t \) – value from a t-distribution [13], see Table I:

\[
t \cdot SE_{\bar{Y}}
\]  

(VII)

The sought after value is then expected to fall within the following range, with a given confidence level [13]:

\[
Range = \text{Estimate} \pm \text{Absolute precision}
\]  

(VIII)

Precision can also be represented in the form of relative precision [13]:

\[
\frac{t \cdot SE}{\text{Estimate}}
\]  

(IX)

The t-value can be taken from the following table [13]:

II
In order to select the correct $t$-value a confidence level needs to be chosen and the correct degrees of freedom, $DF$, need to be calculated. To decide the degrees of freedom for a sample the following equation can be utilized [13]:

$$DF = n - 1$$  \hspace{1cm} (X)

Where:

$n$ is the sample size

And for a regression model the following equation can be used to calculate the degrees of freedom [13]:

$$DF = n - p - 1$$  \hspace{1cm} (XI)
Where:

\[ p \] is the number of independent variables used in the model.
Appendix B – Prescriptive measures for building energy performance

Building energy performance - Prescriptive approach

Meet all of the following prescriptive requirements for all building spaces [41]:

- Glazing: Maximum U value = 0.4 AND maximum SHGC = 0.25
- Exterior Wall R-Value: Minimum R-15+3 c.i. (wood frame) OR R-13+7.5 c.i. (steel frame). Continuous insulation required.
- Roof Insulation: Minimum R-38 for “attic and other” OR R-20 c.i. for “insulation entirely above deck”.
- Floor Insulation: Minimum R-30 for joist/framing OR R-8.3 c.i. for mass.
- Interior Hardwired Lighting: Minimum 90% of all indoor lamps must be Energy Star-compliant, high-efficacy lamps* AND overall lighting power density may not exceed 0.6 W/sqft.
- Mechanical Systems: All split mechanical systems shall be rated at a minimum 15 SEER cooling efficiency AND be heat pumps where the heating source is electric.
- Appliances: Refrigerators and dishwashers must be Energy Star compliant.

*Lighting required for safety, security or eye adaptation is excluded from the calculation.
**Appendix C – Requirements for energy measures for higher star ratings**

Table II: The energy measures available for higher star rating and the requirements needed and points [41].

<table>
<thead>
<tr>
<th>Measure</th>
<th>Requirements</th>
</tr>
</thead>
</table>
| 3.1 a   | Points for energy performance percentage improvements relative to the baseline model:  
          - 4 percent savings (1 point)  
          - 6 percent savings (2 points)  
          - 8 percent savings (3 points)  
          - 10 percent savings (4 points)  
          - 12 percent savings (5 points)  
          - 14 percent savings (6 points)  
          - 16 percent savings (7 points)  
          - 18 percent savings (8 points)  
          - 20 percent savings (9 points)  
          - 22 percent savings (10 points)  
          - 24 percent savings (11 points)  
          - 26 percent savings (12 points) |
| 3.1 b.1 | Prescriptive option: Cooling equipment efficiency  
          All cooling equipment meets one of the following:  
          - 16 SEER (1 point)  
          - 17 SEER (2 points)  
| 3.1 b.2 | Prescriptive option: Heating system efficiency  
          All heating equipment meets one of the following:  
          - Sealed combustion gas furnace  
          - Energy Star labeled heat pump  
| 3.1 b.3 | Prescriptive option: Water heaters  
          All water heaters meet one of the following:  
          - Hybrid/Heat pump water heaters  
          - Gas water heater  
          - Gas Instantaneous Tankless Water Heaters  
          - Solar Water Heaters  
          - Central Gas Boilers  
| 3.1 b.4 | Prescriptive option: Ceiling fans  
          Install Energy Star ceiling fans in all main rooms and bedrooms (not required in walled dining rooms/kitchens).  
| 3.1 b.5 | Prescriptive option: Interior lighting  
          Choose one of the following:  
          - Option A: 100% of all indoor lamps are Energy Star-compliant high efficacy lamps (1 point).  
          - Option B: 20% of all indoor fixtures are LED (2 points)  
          - Option C: 50% of all indoor fixtures are  

VI
<table>
<thead>
<tr>
<th></th>
<th>LED (3 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 b.6</td>
<td>Prescriptive option: Exterior lighting</td>
</tr>
<tr>
<td></td>
<td>100% of parking lighting is LED</td>
</tr>
<tr>
<td>3.2</td>
<td>High efficiency clothes washers</td>
</tr>
<tr>
<td></td>
<td>Choose one of the following:</td>
</tr>
<tr>
<td></td>
<td>• Option 1: Install in every dwelling unit: Energy Star or CEE labeled clothes washer</td>
</tr>
<tr>
<td></td>
<td>• Option 2: If project is not providing clothes washers in unit, provide Energy Star or CEE labeled clothes washers in the central laundry.</td>
</tr>
<tr>
<td>3.3</td>
<td>Variable capacity systems</td>
</tr>
<tr>
<td></td>
<td>For dwelling units sized less than 1.5 tons per Manual J, install Variable Capacity Systems.</td>
</tr>
<tr>
<td>3.4</td>
<td>District cooling</td>
</tr>
<tr>
<td></td>
<td>Tie into a district thermal energy system.</td>
</tr>
<tr>
<td>3.5</td>
<td>Green Energy</td>
</tr>
<tr>
<td></td>
<td>Option 1: Subscribe to Austin Energy’s GreenChoice® program for a minimum one-year and 100% renewable energy contract for the non-dwelling annual electricity use (house meter). OR Option 2: Obtain at a minimum a two-year contract for Texas RECs or other national RECs that are Green-e Energy certified for the non-dwelling annual electricity use (house meter).</td>
</tr>
<tr>
<td>3.6</td>
<td>On-site renewable energy</td>
</tr>
<tr>
<td></td>
<td>Use on-site renewable energy generation to offset building electricity usage. Points are achieved according to the system size:</td>
</tr>
<tr>
<td></td>
<td>• 10 kW PV system (1 point)</td>
</tr>
<tr>
<td></td>
<td>• 15 kW PV system (2 points)</td>
</tr>
<tr>
<td></td>
<td>• 20 kW PV system (3 points)</td>
</tr>
<tr>
<td></td>
<td>• &gt;25 kW PV system (4 points)</td>
</tr>
<tr>
<td>3.7</td>
<td>Additional commissioning</td>
</tr>
<tr>
<td></td>
<td>Option 1 - Comprehensive Commissioning (1 point) AND/OR Option 2 - Thermal Envelope Commissioning (2 points)</td>
</tr>
</tbody>
</table>
Appendix D – Evaluation plan outline and checklist

Evaluation plan outline [12]

Part 1. Program Background

1. Short description of the program(s) being evaluated (e.g., the market, program delivery approach, technologies, budget, objectives)
2. Presentation of how the program will achieve its objectives, the program theory
3. List of the technologies offered by the program
4. Program schedule
5. Numerical energy and non-energy savings projections.

Part 2. Evaluation Overview

1. List of evaluation objectives and how they support program goals
2. List of which metrics will be reported (e.g., annual MWh, monthly peak kW, annual therms, annual CO₂)
3. Description of verification activities
4. Version of the TRM to be used and/or any TRM development/review activities
5. Gross and net impact evaluation approaches selected for determining energy (and demand) savings
6. Methodology for calculating non-energy benefits such as avoided emissions, as appropriate
7. List of primary factors that will be considered in analysis of gross and net savings (e.g., weather, occupancy, free riders, spillover) as well as list of major assumptions
8. Description of how program impact results will be combined to report portfolio impacts, addressing the need for adjustments such as accounting for program overlap or other factors
9. Expectations for overall certainty of savings estimates
10. Assumptions concerning availability of data and other information provided by the administrator/implementer; relative roles of evaluator and administrator/implementer
11. Budget and schedule summary

12. Listing of evaluators (if known) or evaluator selection method

Part 3. Detailed Evaluation Approach, Scope, Budget, Schedule, and Staffing (This is the detailed presentation of evaluation activities to be undertaken, including the evaluation approach to be used.)

1. Gross impact savings analysis—a description of the data collection and analysis activities and approaches (if an M&V evaluation approach is selected, identify the IPMVP option to be used)

2. Net impact savings analysis—a description of how spillover, free ridership, and other effects will be addressed in the evaluation activities and in the data analysis (as appropriate)

3. Data collection, handling, and sampling:
   a) Measurement collection techniques
   b) Sampling approach and sample selection methods for each evaluation activity that includes sampling efforts (as appropriate)
   c) How the comparison group or non-participant information will be used in the evaluation(s) and in the analysis (as appropriate)
   d) Data handling and data analysis approach to be used to address the researchable issues

4. Uncertainty of results—presentation and discussion of the threats to validity, potential biases, methods used to minimize bias, and level of precision and confidence associated with the sample selection methods and the evaluation approaches; quality control information should also be included here

5. An activities timeline with project deliverable dates, including reporting activity and key milestones, including communications with administrator/implementer

6. Detailed budget and schedule.

7. Evaluation team—information concerning the independence of the evaluator.

**Evaluation report outline**

The final product or output of an evaluation is an evaluated savings report. The following is a sample report outline:
• List of Figures and Tables
• Acronyms
• Abstract
• Acknowledgments
1. Executive Summary (Include highlights of key recommended improvements to the program, if relevant)
2. Introduction
   • Program Overview (e.g., program description, objectives)
   • Evaluation Objectives and Methods
   • Report Structure
3. Study Methodology
   • Data Collection Approach(es)
   • Analysis Methods
   • Limitations, Caveats
4. Key Evaluation Results with metrics and realization rates (answers for all of the questions specified for the evaluation. This could include several sections on findings. Findings could be presented for each method used, by program components covered, by market segments covered, and so forth, followed by a section on integrated findings or organized and presented by the different observed effects or type of results.)
5. Synthesis of analysis and findings as well as implications of findings
6. Recommendations (should include clear, actionable, and prioritized recommendations that are supported by the analysis)
7. Summary and Conclusions
8. Appendices (examples listed below):
   • Recommended improvements to the evaluation process, including any lessons learned for future evaluation studies
   • Detailed documentation of the research design and assumptions, data collection methods, evaluation analysis methodology, references, and results tables
• Survey or interview instrument, coding scheme, and compiled results tables and data
• Sources and quality (caveats on data) of primary and secondary information
• Details on quantitative data analysis: analytical framework, modeling approach, and statistical results
• Qualifications to results
• Possible sources of overestimation and underestimation
• Analysis of reliability of energy savings estimates, treatment of issues that threaten reliability of results (e.g., double counting, use of savings factors, and synergistic effects)
• How attribution was addressed (for net savings impact evaluation)
• Other assumptions and justifications.
### Evaluation planning checklist [12]

#### Checklist for gross savings determination

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings to be reported</td>
<td></td>
</tr>
<tr>
<td>Energy savings (annual, seasonal, monthly, hourly, other)</td>
<td></td>
</tr>
<tr>
<td>Demand savings (peak, coincident, average, other)</td>
<td></td>
</tr>
<tr>
<td>Selected gross energy savings calculation approach</td>
<td></td>
</tr>
<tr>
<td>Measurement and verification approach</td>
<td></td>
</tr>
<tr>
<td>Deemed savings approach</td>
<td></td>
</tr>
<tr>
<td>Large-scale billing analysis approach</td>
<td></td>
</tr>
<tr>
<td>Quality assurance approach</td>
<td></td>
</tr>
<tr>
<td>Measurement and verification approach</td>
<td></td>
</tr>
<tr>
<td>IPMVP Option A, B, C or D</td>
<td></td>
</tr>
<tr>
<td>Deemed savings approach</td>
<td></td>
</tr>
<tr>
<td>Source of deemed savings identified and verified</td>
<td></td>
</tr>
<tr>
<td>Large-scale billing analysis approach</td>
<td></td>
</tr>
<tr>
<td>Randomized controlled trials</td>
<td></td>
</tr>
<tr>
<td>Quasi-experimental method</td>
<td></td>
</tr>
<tr>
<td>Sample size criteria selected</td>
<td></td>
</tr>
<tr>
<td>Lifetime energy and demand savings factors to be evaluated</td>
<td></td>
</tr>
<tr>
<td>Degradation</td>
<td></td>
</tr>
<tr>
<td>Rebound</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

#### Checklist for net savings determination

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net savings factors to be evaluated</td>
<td></td>
</tr>
<tr>
<td>Free riders</td>
<td></td>
</tr>
<tr>
<td>Spillover effects</td>
<td></td>
</tr>
<tr>
<td>Other market effects</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Net savings calculation approach selected</td>
<td></td>
</tr>
<tr>
<td>Self-reporting survey</td>
<td></td>
</tr>
<tr>
<td>Enhanced self-reporting survey</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>Large-scale consumption data analysis approaches (randomized controlled trials and quasi-experimental methods)</td>
<td></td>
</tr>
<tr>
<td>Stipulated net-to-gross ratio</td>
<td></td>
</tr>
<tr>
<td>Cross-sectional studies</td>
<td></td>
</tr>
<tr>
<td>Top-down evaluations (or macro-economic models)</td>
<td></td>
</tr>
</tbody>
</table>

### Checklist for avoided emissions calculations

<table>
<thead>
<tr>
<th>Electricity efficiency savings – grid-connected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load emission rates</td>
</tr>
<tr>
<td>Regional marginal base load emission rates (using capacity factors or equivalent)</td>
</tr>
<tr>
<td>Energy scenario modeling</td>
</tr>
<tr>
<td>Natural gas, fuel oil and non-grid-connected electric generating units</td>
</tr>
<tr>
<td>Default emission factor</td>
</tr>
<tr>
<td>Source testing</td>
</tr>
</tbody>
</table>

### Generic evaluation considerations (examples)

<table>
<thead>
<tr>
<th>Overall goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the evaluation address the key policy, regulatory, and oversight needs for evaluation information?</td>
</tr>
<tr>
<td>Will the program’s success in meeting energy, demand, and emissions goals be quantifiably evaluated in the same manner as they are defined for the program?</td>
</tr>
<tr>
<td>Does the evaluation plan represent a reasonable approach to addressing the information needs?</td>
</tr>
<tr>
<td>Are there missing opportunities associated with the evaluation approach that should be added or considered? Are any additional non-energy benefits being evaluated?</td>
</tr>
<tr>
<td>Does the impact evaluation provide the data needed to inform other evaluations that may be performed, particularly cost-effectiveness analyses?</td>
</tr>
<tr>
<td>Has a balance been reached between evaluation costs, uncertainty of results, and value of evaluation results?</td>
</tr>
<tr>
<td>Uncertainty of evaluation results</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Can the confidence and precision of the evaluation results be quantified? If so, how?</td>
</tr>
<tr>
<td>Are there key threats to the validity of the conclusions? Are they being minimized given budget constraints and study trade-offs? Will they be documented and analyzed?</td>
</tr>
<tr>
<td>Is the evaluation capable of providing reliable conclusions on energy and other impacts?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Budget, timing and resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the evaluation take advantage of previous evaluations and/or concurrent ones for other programs?</td>
</tr>
<tr>
<td>Does the cost of the study match the methods and approaches planned?</td>
</tr>
<tr>
<td>Do the scheduled start and end times of the evaluation match the need for adequate evaluation?</td>
</tr>
<tr>
<td>Are adequate human resources identified?</td>
</tr>
<tr>
<td>Does the evaluation rely on data and project access that are reasonably available?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are the time frames and scopes of evaluation reported defined?</td>
</tr>
<tr>
<td>Do the data collection, analysis, and quality control match the reporting needs?</td>
</tr>
<tr>
<td>Are the persistence of savings and avoided emissions being evaluated?</td>
</tr>
<tr>
<td>Have measurements and impacts (emissions) boundaries been properly set?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling and accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the sampling plan representative of the population served?</td>
</tr>
<tr>
<td>Is the sampling plan able to support the evaluation policy objectives?</td>
</tr>
<tr>
<td>Are there threats to the validity of the evaluation results addressed in the sample design?</td>
</tr>
</tbody>
</table>
Appendix E – Excel sample size calculation spreadsheet and manual

1. Upload data
   1) Upload data for the buildings from the start year you are interested in to the most resent building to go through the program.
   2) The following data is needed in the following order:
      - Savings reported date
      - Project name
      - Star rating
      - Total number of units
      - Square footage
      - kWh saved
      - kW saved

3) Don’t fill column A ("Criteria #1") with data.
2. Sorting the data

1) Now we will test the data for Criteria #1, buildings that have at least one full year of utility data. Do this by clicking the A2 cell, like in the picture above. Then go to Developer → Macro → Criteria 1 → Run. This will result in a 0 in column A for all buildings that do not have a full year of utility data and a 1 for all who do.

2) Next we will delete all cells in column A that have been filled but do not have a building. Do this by going to Developer → Macro → DeleteRowsThatAreEmptyInColB → Run.

3) Next we will delete all buildings from the spreadsheet that do not have a full year of utility data. Do this by going to Developer → Macro → DeleteRowsWithZerosInColA → Run.

4) To make sure those buildings that have not reported any savings are not included in the sample we will exclude all buildings that have reported 0 kWh of saved energy. Do this by going to Developer → Macro → DeleteRowsWithZerosInColG → Run.

5) Next we will sort the data. First after Star rating and then after square footage. Do this by highlighting all the cells that have information in them, including the top row. Then click on the Sort & Filter button → Custom Sort → OK. It should now have sorted by Star rating first, from smallest to largest and then by square footage from smallest to largest. (This is not necessary for the calculations but can give a better overview of the data.)

We are now finished sorting the data and it can be found under the “Data” workbook, see picture below.
3. Select precision, confidence level and coefficient of variance

1) Next the precision, confidence level and coefficient of variance need to be selected. Move to the next worksheet, “Initial Sample Size and Data”. From the drop down lists in the cell below “Relative precision”, choose the desired precision. Do the same for confidence level and coefficient of variance. If the coefficient of variance is not known it is recommended to use 0.5 for the initial sample size.

2) This will automatically calculate the Initial sample size and the sample size with the finite population correction.
4. Simple random sample size and stratified random sample size

1) Now the simple random sample size and the stratified random sample size have been calculated automatically. To see them move to their respective worksheets, “Simple random sample” and “Stratified random sample”, see pictures below.