FINAL REPORT

The Viability of Commissioning in New School Construction

Prepared for

The Northside Independent School District

and

The Texas State Energy Conservation Office

by the

Brooks Energy and Sustainability Laboratory
The Texas Center for Applied Technology
Texas Engineering Experiment Station

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Executive Summary

There is ample anecdotal evidence that commissioning benefits exceed its costs. However, there is a shortage of concrete documentation of those costs and benefits, or even information as to where the costs and benefits lie. Without this kind of evidence, it is very difficult to communicate the value of commissioning services to potential customers, which is one of the key barriers to establishing commissioning as a standard practice. Therefore, the objective of this study was to document the costs and benefits of commissioning in one school and to effectively relate these “differences” to a similar educational facility that was not commissioned. In the course of the study much was learned as to the types of benefits expected and realized from the commissioning process. Of a secondary nature, but of no less importance, was the observation by researchers as to the overall acceptance and process appeal for the commissioning activity, and its *perceived* benefit to the design/construction process. The State Energy Conservation Office (SECO) of the Texas Comptroller of Public Accounts and the U.S. Department of Energy has funded this study of the costs and benefits of commissioning of new school facilities. This study involves close investigation of two schools: one school recently constructed and commissioned, and a similar school that was also recently built without benefit of commissioning.

For this study, the selected approach to investigate and isolate the benefits of commissioning was to target the Mechanical, Electrical, and Plumbing (MEP) systems in a commissioned building and evaluate performance, while at the same time evaluating the performance of these systems in a similar “baseline” building. Researchers looked at historical information as well as real time data in the areas of planning, design, construction, operation, post-occupancy maintenance, warranty service, customer satisfaction, and energy consumption for both buildings in the study. Building energy models were used to assist in energy analysis and equipment operation and selection. Metrics in each area were identified and reported values were “normalized” for ease of comparison.

For the commissioned facility, significant reductions in the number/cost of MEP related change orders were noted. Numbers of change orders dropped by a factor of three, while cost of these change orders was reduced almost 45 percent. Post occupancy MEP work accomplished by maintenance and operations staff in the commissioned school showed significant improvement with overall numbers of work orders decreasing by 50% in the first six months of occupancy and material and labor costs for these work orders decreasing by almost 60%. Energy analysis performed on both facilities indicated that the commissioned facility cost the school district an average of $0.016/sf less per month to operate than the baseline building; a documented savings in excess of $16,000.00 annually. Based solely on this single, quantifiable result, the derived payback for this facility was 5.2 years. Quantifying and incorporating other noted improvements in post construction maintenance/operations and occupancy issues would reduce this payback period to below that already noted above. With these and other points mentioned in the report, the benefits of commissioning became apparent to district staff and researchers alike.

Based on items mentioned above, and developed in more detail throughout this report, this study indicates a direct benefit of commissioning to Northside Independent School District and for all other school districts in the State of Texas. Given the skilled and motivated staff within this District, coupled with their process of school construction which remains at a level of continuous activity, the fact that commissioning resulted in measurable and marked improvements is noteworthy. For the vast majority of small school districts in Texas that have less formidable engineering and construction expertise within the organization, commissioning benefits could expect to provide increased cost savings and process improvements relative to past projects. Therefore, this study views the commissioning process as a viable and cost effective method to improve facility design and construction and reduce operational utility expenses.

Acknowledgements

This study was a collaborative effort by many individuals associated with numerous organizations, and it would be impossible to name each and every member that took part in and contributed to this project.

We would however like to thank the State Energy Conservation Office (SECO) for funding this important study and in particular, Mr. Felix Lopez, the SECO Program Manager, responsible for providing guidance and helping the project stay on track.

At Northside Independent School District (NISD) we would like to thank Mr. Joe Martin, Director of Engineering, Mr. Ceasar Ponce, Director of Facilities Construction, Mr. Bernie Morin, Director of Maintenance and Operations, and their respective staff members who directly supported many of the tasks necessary for successful completion of this study. Highly instrumental in facilitating this study was Mr. Frank Thomas, the NISD Energy Manager, assisted by Mr. Bruce Dschuden. Appreciation goes out to Mr. Jim Martin, Assistant Superintendent for Facilities and Operations who supported this study through meeting attendance, insightful comments, and through the efforts of his personnel. We also want to extend our thanks to the faculty and staff at the schools who were patient with our on-site forays.

Finally, thanks to Dr. Kristin Heinemeier for being the “lightening rod” and organizer for this study. Her initial efforts at developing a methodology were the blueprint for conducting this worthwhile effort.

Introduction

The facility/equipment commissioning process as practiced by professionals today has many similarities to quality assurance (QA) efforts performed in other industries. Commissioning is a well known process whereby commissioning professionals verify building systems/components as well as functionality and operation against owners and designers intent. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines commissioning as “a quality oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.” A key difference in commissioning and traditional QA programs is the wide variability in facility parameters (i.e., design specifications, size, installed equipment, construction process, etc.) which are obvious to the trained engineering/construction professional.

For any “new construction”, the commissioning process ideally begins in the early planning stages of a building, and continues through the turnover and early occupancy. A key player in this process is the Commissioning Authority (CA), who coordinates, communicates, and documents efforts by others in the design and construction teams, and acts as the vanguard of quality improvement for the building owner. Commissioning professionals in the industry are already aware of numerous projects where the commissioning process has paved the way for efficient, energy smart facilities. Unfortunately, convincing, scientific evidence is sparse. This "anecdotal only" approach to convincing building owners/managers makes the commissioning process a "hard sell" in the real world metrics of cost versus benefit. The primary difficulty in promoting this technology reduces down to the inability to link expected savings from commissioning to commissioning costs. A further impediment to commissioning is the general understanding, or lack thereof, held by the majority of laymen in realizing the immediate as well the out year benefits of the commissioning process. Therefore in promoting commissioning technology as a business, it is difficult to convince potential commissioning customers to spend an uncertain amount of money to purchase an unknown service with unknown savings.

From the current discussion it is clear that to successfully promote commissioning it must be shown 1) what are the costs incurred in a facility where commissioning has not been undertaken versus a commissioned facility, and 2) can any benefits that arise be attributed to the commissioning process. The design process, communication and management in the construction process, changes made throughout the process, and ongoing maintenance are some of the important contributors to the cost of delivering a building. Because of this, expected benefits can take many forms from reduced energy consumption, fewer warranty service calls, improved response to design/construction issues, or fewer work orders submitted, all of which must be documented in order to successfully “make the case” for commissioning. It is the goal of this study to bring together these factors in a side-by-side comparison of two facilities in an attempt to shed light on just some of the benefits.

The Texas State Energy Conservation Office (SECO) has a fervent interest in promoting energy efficiency technologies in buildings throughout the state, as well as a desire to ensure the

appropriateness of any technologies they promote. Because of this interest, SECO funded this study to ascertain the costs and benefits of commissioning.
They provided funding directly to the Northside Independent School District in San Antonio to pay for both the commissioning and the study. The District contracted with the Brooks Energy and Sustainability Laboratory (BESL) to conduct the study. BESL then acquired the services of Testing Specialties, Inc, as the Commissioning Authority (CA) for the study.

The objective of this study was to document the costs and benefits of commissioning in one school and effectively relate these "differences" to a similar educational facility that was not commissioned. In the course of the study it is expected that much will be learned as to the types of benefits expected and realized from the commissioning process. Of a secondary nature, but of no less importance will be the observation by researchers as to the overall acceptance and process appeal for the commissioning activity, and its perceived benefit to the design/construction process. Because a study of this nature has not been undertaken to date, and the fact that commissioning provides benefits in a sometimes complex and abstract way, there was also a need to develop methodology for identifying the benefits and metrics for quantifying them.

Methodology

General Background

For this study, the selected approach to investigate and isolate the benefits of commissioning was to target the Mechanical, Electrical, and Plumbing systems (MEP) in a commissioned building and evaluate performance, while at the same time evaluating the performance of these systems in a similar "baseline" building.

The commissioning study was conducted in a suburban school district in San Antonio. This is a very large school district with approximately 82,000 students and 98 facilities comprising over 8 million square feet. This area is growing rapidly, and bond issues of almost a billion dollars have been passed in the last decade for facility construction. Over a million square feet of facilities have been constructed within the last two years or are currently under construction.

Based on the obvious fact that only two schools were chosen for the study, it should be apparent that this was not an attempt to conduct a statistically significant experiment. The choice was rather to design a more qualitative study; to identify and document the nature of the costs and the benefits in detail as well as any associated "gains" from the commissioning process whether quantifiable or intangible. The goal was to quantify benefits where possible, to estimate their magnitude when quantification was not possible, and to simply identify their presence when estimation was not possible.

At the outset of the study, significant consideration went into the selection of a suitable baseline school to serve as a comparison to the commissioned school. The commissioned school selection was already based on the next facility in the design/construction queue for the District. For this facility, only the location and programmed square foot area were known. Working closely with school district staff, a complete picture of recently constructed and existing facilities was compiled. Ideally, the objective was to minimize extreme variability in design/construction as much as possible. That being said, anyone familiar with the design/construction industries is aware that even with all the "same players", the process may be unpredictable and quite dynamic requiring constant management and oversight.

Figure 1 shown on the following page provides a graphic representation of the overall study as it was conceived early in the process and is presented here for reference. Much emphasis was placed on the study process in order to gather sufficient information for analysis at a later stage in the study. Ideally, the process was developed to allow parallel tasking to be accomplished by the study team. This would make the best use of manpower and also facilitate some instant feedback to team members to provide for process improvement "in midstream". Further discussion of individual tasks as they relate to the study, as well as supporting background information will be addressed later.

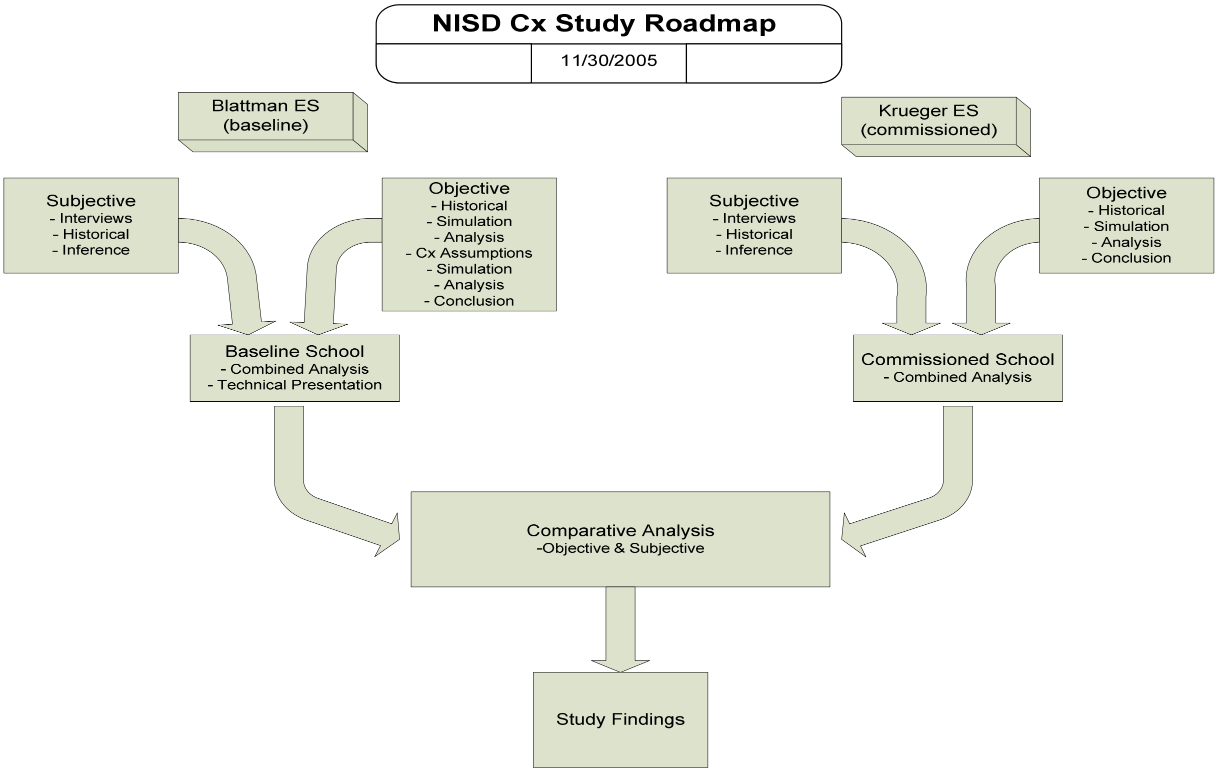


Figure 1. Schematic for Commissioning Study/Process Flow Diagram

Those items that were of paramount importance in selecting the baseline school was that it be recently built and have similar style, size, schedule, and mechanical systems. Beyond this, any further similarities were only desired expectations on the part of the researchers. Table 1 shown on the proceeding page identifies general characteristics of these two schools, reflecting information known and provided shortly after the start of school design/construction. It should also be noted that both schools were initially designed to house 660 students, although early in the design stage a decision was made to add 140 students to the commissioned school thereby adding approximately 15,000 sqft to the building footprint.

Table 1. Characteristics of Baseline and Commissioned Schools

Characteristic	Baseline School	Commissioned School
floor area	86,000 sqft	100,800 sqft
number of students	660	800
expected construction cost	$10,400,000	$11,200,000
year design was started	2001	2003
year of first occupancy	2003	2005
type of mechanical system	air-cooled chillers, air-handling units, fan-powered boxes,	same type of systems
air conditioned gymnasium	initially designed to be ventilated, conditioning added as change order	air conditioned
energy code	not applicable	IECC 2000
architect	first new school for this district	same architect
general contractor	well established with district	worked previously in district
major subcontractors	well established with district	well established with district

In retrospect, it was fortunate that a major key expectation was realized in that the Architectural Design firm and the MEP Engineering firm were both knowledgeable of the District's design/construction process. Both the A/E and the mechanical designer were also familiar with the District's design guide and master specification. This was attributed to the fact that both the A/E and the MEP designer were utilized on both of the elementary schools selected for this commissioning study. This allowed, to some extent, the idea that many key elements of design, equipment/material selection, and sequence of operation would be relatively constant. Also considered a positive factor, was the fact that the baseline school had been recently constructed and that key design elements which tend to evolve in any agency had remained intact in the school district design guidance document.

Data Sources
Table 2 shown below provides a brief description of the types of information that was collected and tracked or analyzed for this evaluation.

Table 2: Information Sources from Baseline and Commissioned Schools

Construction Documents	Specifications, as-built drawings, initial and final project schedules, change orders, requests for information, design review minutes, and construction meeting minutes. These were all used to establish a narrative description of the construction process in the baseline/commissioned school, and to identify the cost and schedule impacts of issues that were encountered.
Construction Process Interviews	Interviews with key staff members were conducted to interpret the documents and to provide other information; what took place and the impacts. Interviews included the architect, NISD Construction Director, Engineering Director, Maintenance Director, and the Energy Manager.
Lessons Learned Workshop	Part of the process being recommended for commissioning is to hold a Lessons-Learned workshop for previously constructed facilities, if applicable. Therefore, as part of the commissioning process for a new school, holding a Lessons Learned Workshop for the baseline school was accomplished. This serves a dual-purpose: to provide valuable lessons to improve the commissioned school and to provide information for the study on benefits that would have been gained at the baseline school.
Occupant Satisfaction Interviews	We conducted in-depth interviews of key personnel halfway into the first year of occupancy. These interviews helped to identify some of the issues that occurred with the building during the “shake-out” period, while the issues were still fresh in the occupants’ minds. These interviews covered topics such as thermal comfort, lighting, and indoor environment acceptability. The interviews were conducted with the school principal, several representatives of the teachers or administrative staff, and the head custodian.
Work Orders	Work Order data was a source of quantitative information regarding the amount, nature, and cost of maintenance required. It was used to evaluate and document any reduction in operating costs due to reduced maintenance. These data were obtained halfway through the first school year of occupancy, and will be reviewed again at the end of the first full year of occupancy.
Utility Bills	Gas and electricity bills are collected by the district, and tracked in an energy accounting system. Reports were generated from this system for our analysis. These data will be used to evaluate the difference in energy costs. Data were collected after the first six months of occupancy, and on an on-going basis thereafter. They will be reviewed and trended for the first school year of occupancy for the both schools. For analysis, energy use data was normalized for square footage, weather, occupancy, and schedule differences.
Metered Data	Evaluating reductions in energy costs requires more detailed energy consumption data than monthly utility bills can provide. Therefore 15-minute interval data for the utility meters for both schools was used.
Building Walk-thru	The schools were toured halfway through the first year of occupancy, with an eye towards any deficiencies in design, installation, function, or other factors that could affect building operation.
Observation	In addition to the qualitative and quantitative data described above, many benefits were documented through observation. The observations of the study and commissioning team were logged using a database to collect information regarding the nature of the observation, the area in which it was observed, and expected implications of the observation. Observations were reviewed to identify any repeat or significant issues.

This was not expected to be a study of the "best case" for commissioning. A best-case scenario might involve an owner who had conducted commissioning many times, and design and construction teams who were already familiar with commissioning. This might serve to highlight the ease with which commissioning could be integrated into existing practices as well as various project design/construction benefits. Another best case might involve a school district where current design/construction policies and procedures were lacking, and commissioning would provide a more significant improvement over standard, past practice. In this study, neither of the aforementioned cases applies. Instead, the selected school district was unfamiliar with the standard practices surrounding the commissioning process, although the majority of staff was acquainted with the concept through trade journals and professional development courses. In the case of this particular study, the school district already had a well developed engineering design guide to ensure minimum standards and best practices were upheld on all new construction and major renovation projects. Also, the size of the district engineering and construction departments with it's cadre of skilled staff had developed extensive checks and balances throughout the process to ensure adequate support during the new school construction process. This made the case for "proving commissioning" a difficult one, since recently constructed facilities were already considered above par with respect to other campuses within the district as well as many other schools in the local area.

It will be mentioned briefly at this point, and later in detail, that two significant factors are assumed to have impacted the overall performance/outcome of commissioning at Krueger ES. The first and most important factor was that of school selection and timing. The campus selected for commissioning was already under design when it was selected for the study, and therefore, the commissioning agent was behind before they began. As commissioning is currently understood, one main area of impact is in the facility design process. Being unable to totally accomplish this and provide input from the very start of design makes the project outcome, from a commissioning perspective, less than ideal. Due in part to this late start, and the extensive school design guide already in place, partially contributed to an inability at implementing some of the elements considered important for commissioning. This was recognized early in the process and not pursued because of the need to respect the District's current procedures and timelines. Therefore, in addition to the benefits actually observed in performing the comparison study, later mention will be made as to potential benefits that could be achieved under more ideal circumstances. As an additional important note, the owner is considering commissioning in future schools, based on the preliminary results of this study.

Metrics for School Performance

The methodology used to document benefits would normally be a detailed side-by-side case study with a large sample size. Although only two buildings are included in this study, the depth of this analysis provides the opportunity not just to collect key metrics, but to understand what happened and why. Commissioning is a complex process providing benefits in sometimes abstract/intangible ways.

A detailed understanding of the process of designing and constructing a building, and the ways that commissioning improves both the process and the resulting building, are key to communicating the benefits. In addition, potential customers of the commissioning process may have multiple objectives and varying goals in mind when undertaking, and paying for, the process. Because of this reason, an effort was made to look at all potential avenues of success that might be associated with the commissioning process. Another reason might be to enlighten building owners and operators to the numerous areas where proper commissioning might provide a positive impact, both financially (e.g. direct energy savings, reduced service calls), and from a building occupant's perspective (e.g. comfort, improved environment).

To describe the quality of the process and the building in more than an anecdotal way requires more than a simple qualitative analysis. Metrics need to be identified to capture the performance of the process. Also, some measure of overall building satisfaction and performance (post construction) must be defined. This report has outlined a set of metrics that are relatively easy to collect, and that appear to capture the performance of the process and the completed building in a conventional construction project setting. These metrics should be useful in comparing the baseline project with the commissioned school. Hopefully, these metrics will be the basis for an expanded understanding of performance, and contribute to future guidelines for collecting performance data to support comparisons between commissioned and uncommissioned facilities nationwide. It is hoped that metrics such as those presented in this report can be incorporated in this and future protocols and that large data collection efforts can be undertaken. Additional scrutiny by industry professionals should be done, however, to investigate the reliability and usefulness of these proposed metrics in comparing different projects.

Requests for Information (RFI)

The Request for Information is the formal mechanism for the contractor or subcontractor to ask for clarification on a design element, to comment on items that may not operate as designed, or to suggest an alternative design or specification. RFI's are submitted during a construction meeting, a date for clarification is requested, and a response is issued. All of these steps require paperwork, tracking, and some amount of time at a construction meeting to discuss or resolve. For example, even a simple RFI may take a half hour to prepare, 10 minutes to discuss at a construction meeting with 10 individuals in attendance, and 10 minutes at the next meeting to discuss the results. This equates to almost four man-hours of effort.

RFI's may be the result of unclear/unfamiliar designs, inappropriate design, incomplete understanding of the documents provided to the contractor, or the understandably improved perspective of the contractor once building construction is underway.

Hence, RFIs can be seen as a negative (unclear or incorrect design), or as a positive (everyone working as a team to come up with the best design). If the commissioning process is undertaken at an early stage in the design, it is anticipated that some design clarifications will be accomplished at this time.

This would be a logical assumption stemming from the fact that another professional, versed in design and construction will review, analyze and contribute to the projects design and provide observations that will alleviate subsequent requests. It can also be expected that commissioning will facilitate in later completed design review and construction communication processes, so that unnecessary RFI's can be reduced and constructive requests can be facilitated, resolved, and processed in a more timely fashion. For this study, RFI logs were collected and analyzed for both schools and results will be presented in appropriate sections later in this report.

Change Orders (CO)

Change orders accommodate situations where the work required by the contractor is different from what was assumed during the bidding process. Change orders can result from a variety of situations. They can be due to unforeseen circumstances (such as unexpected and/or varying conditions at the site), a change in requirements by the designer or owner (such as a desire to add/remove equipment), material delivery availability, project scheduling, or in response to an RFI issued during the construction phase. Situations which might result in a change order are too numerous to mention here and the circumstances above are provided only for example purposes. In this project, the owner has included a set aside amount in the project budget which includes a contingency allowance to pay for any change orders that arise. When a proposed change order is issued, the contractor is asked to provide a proposal to supply the additional labor and materials. If accepted, the cost is deducted from the contingency allowance and added to the contractor's disbursement. A change order might just as well result in a credit to the owner under certain circumstances. As in the case of RFI's, some change orders might be alleviated through additional review of design and clarification of project specifications prior to the start of construction. In addition to the added material and labor costs normally associated with change orders the impact on construction schedule may in some cases be more detrimental to overall project completion. Change order logs and their final resolution/cost were tracked as part of this study. Results will be addressed as they pertain to each individual school in appropriate sections of this report.

Punch List

The punch list is the result of an on-site inspection that includes both contractors and owner's representatives which takes place near the end of the construction phase in order to declare and certify the project as "Substantially Complete". Any remaining items that are not considered complete or require additional attention are noted, and a list is generated and provided to the contractor. It is understood by all parties involved that these items must be finished prior to consideration of the project being fully complete and ready for "Final Inspection". At the point of creating and working through the punch list, the contractor is typically very eager to be complete on the project (as this may be tied to final payments) and the owner is understandably eager to take possession of the building. It may be tempting for both sides to overlook issues that should be resolved.

This has its own consequences in that it may generate significant work for the owner during the initial occupancy period and/or necessitate numerous warranty service requests to the contractor. Needless to say, everybody is happier when these issues are dealt with earlier in the project, and not left until this late date for accomplishment.

Project Timeline

With regards to this specific project, it can easily be asserted that the timeline for project completion was the single most relevant driving factor in the process. For any major school district, the school term is a fixed number of days and therefore the opening of a new school facility based on this timeline is considered the bottom line. All effort is expended and costs may increase substantially since equipment and staff must be prepared in advance of the student's arrival. Previously mentioned RFI's and change orders are often times weighed in light of potential scheduling impacts and associated costs. Weather delays which are normally included in any significant construction project are tracked closely by the owner, and contractors are generally pressed to get the facility envelope complete and "dried in" so that interior work can proceed. Overall project timelines were documented, and any noted delays were logged and tracked for both schools to gather the necessary background data for future comparison. For the school which was already complete, this information was part of the historical record gathered from the district and the Architect/Engineer (A/E) firm. With respect to the commissioned school under design/construction it provided a means of recording those significant delays which are considered unavoidable. For the purpose of the study, it was also a means of determining whether the commissioning authority observed project scheduling issues and proposed workable solutions to these delays which were later adopted by the general contractor.

Occupant-Reported Problems

These issues generally arise during the initial occupancy of the facility with the majority being identified during the first six months to one year after moving into the building. They may be the result of design and/or construction deficiencies. They may result from unaddressed punch list items. They may be the result of previously unidentified requirements on the part of the *owner* either during the design and/or construction phase, or on the part of *facility staff* after taking possession of the building. As is evident, the cause of "customer complaints" varies, while the "overall level of satisfaction" with the facility is considered the yardstick. Survey methods were used in this study to determine the level of satisfaction that occupants had with their respective facilities. It should be mentioned however that these responses are highly subjective and do not reflect overall project design/construction integrity. Many of these user identified problems are later characterized as warranty service issues and some are categorized as work orders to be accomplished by maintenance and operations staff. A portion of these may be evaluated and resolved at the campus level without being elevated to administration. Since these items are reported and tracked by district personnel, it is necessary to evaluate each occurrence and determine the nature of the problem, a root cause if possible, and resolution of the discrepancy.

Warranty Service/Work Orders

This measure is closely tied to the previous category mentioned above. Facility operation during the initial stages of occupancy typically generates discrepancies which may be attributed to the recently completed construction process. These discrepancies may be related to specific equipment, general workmanship, installation errors, or operational settings within the building. They may be identified by building occupants, maintenance personnel, construction inspectors, the commissioning agent, or contractors visiting the site.

In any event, these items are logged and tracked from initial identification through resolution. Items that are considered warranty service issues are referred to the appropriate contractor or equipment vendor. Significant interest is placed on warranty service problems specifically as they relate to occupant comfort as well as any high dollar equipment items that may be affected (e.g. chillers, air handlers, etc). Work orders result from non warranty items and are referred to the appropriate maintenance trade for further action.

Significant numbers of work orders would indicate a trend, particularly in a new school, that design and/or construction problems may be a contributing factor. From a monetary standpoint, excessive amounts of work orders may increase maintenance backlog and time to completion, and is generally something that is not considered beneficial in a newly constructed facility. Oversight through the commissioning process is expected to provide some positive impact on this measure since commissioning activity increases observations during the construction process. It also adds an additional level of functional and performance testing which further helps identify and wring out potential issues prior to occupancy. Warranty service logs as well as work order information was provided by the M&O department for each school for a period of one year post construction. This information was analyzed and pertinent numbers and costs were reported for items in the mechanical, electrical, or plumbing trades.

Energy Use

This area is one that can be considered to have both a qualitative as well as a quantitative component. Since much anecdotal evidence has been catalogued concerning the efficacy of commissioning, more data is required on the cost benefit aspect of this emerging process. The impact of commissioning on facility energy consumption is one area where this can be undertaken. The use of computer modeling and simulation can readily compare changes in facility operation as a function of energy use; equipment modifications/upgrades, and faulty installation of components can also be directly linked to either increased or decreased energy expenses. When commissioning takes the lead in optimizing building performance from design through construction, it is expected that lower utility costs will prevail. Based on these assumptions, energy expenses for both schools will be normalized and compared for any significant trends. Additionally, any recommendations with respect to energy consuming equipment that are attributable to the commissioning process will be noted. Programs used for this portion of the study include AirModel (developed at Texas A&M University), EnergyPlus™ (developed for the Department of Energy), and Microsoft Excel to perform data transformations and provide charts and other graphical interpretations. Since the specific cost of commissioning is known for this project, a simple return on investment analysis will be used to highlight payback.

Baseline Building – Blattman Elementary School

The following section will provide background and data gathered for the selected baseline school which was not commissioned during this study. As mentioned earlier in this report, great efforts were taken in the selection of this school in hopes of minimizing differences with the commissioned facility (see Methodology). Results of the study and comparative analysis are reserved for later discussion in this report.

Facility Description

A detailed description of the facility and its installed systems and components is considered beyond the scope of this report, and is not required for an understanding of this study and therefore will not be undertaken. A rudimentary idea of the facility is addressed to provide background as to the project and acquaint the reader with basic details for future reference. The baseline school is single storey, multi-wing facility belonging to Northside Independent School District located in San Antonio, Texas. A footprint of the facility is shown in Figure 2 below.

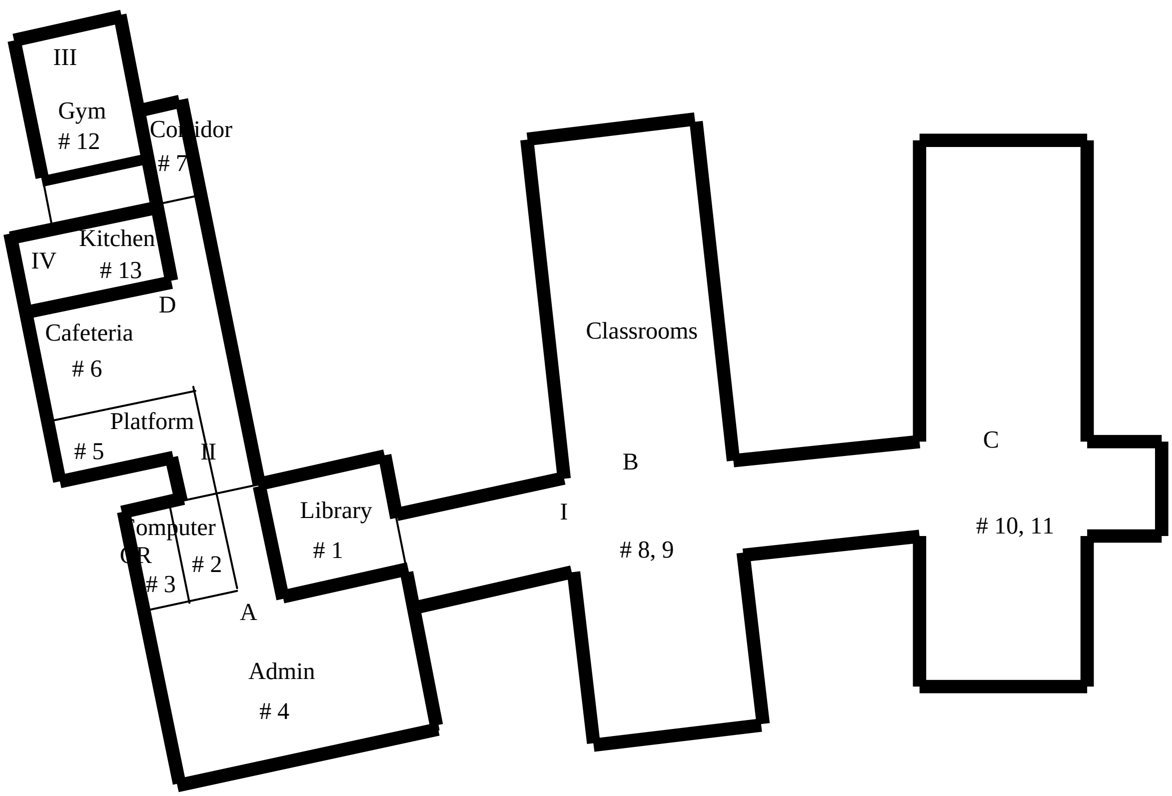


Figure 2. Baseline School Footprint - Patricia Blattman Elementary School

This school houses those functions typically found in any modern elementary school, e.g., classrooms, library, administrative offices, cafeteria, auditorium, and gymnasium. The area of this facility is approximately 86,000 sf with all areas being considered as conditioned space. Environmental comfort is provided by two air cooled, screw type chillers located in the mechanical yard and having a nominal rating of 235 tons cooling per unit. Smaller package cooling units (rooftop or pad mount) are also present to satisfy specific zones within the building.

Figure 3. Air cooled chillers, and DX unit (typical) at Blattman Elementary School

Figure 4. Kitchen area with appliances; typical classroom lighting

A total of thirteen air handling units (AHU) force conditioned air to both constant volume and variable air volume terminal units throughout the school. Five AHU's are equipped with variable speed drives to reduce fan speed and conserve energy when cooling/heating set points are satisfied. Heating is accomplished by means of a single 200 horsepower boiler which provides hot water to selected AHU's as well as zone terminal units within the building. Duty cycling of major components and system scheduling (set point, on/off, setback) is controlled by the district's energy management and control system (EMCS).

The majority of light fixtures inside the building are recessed grid, F32-T8 fixtures with 2, 3, or 4 bulbs depending on application. High pressure sodium and metal halide fixtures round out the remainder of lighting components installed at the school. The architect also made ample use of day lighting in areas where applicable such as classrooms, entryways, and vestibules. As expected, a large plug load is evident in the kitchen area due to the significant number of appliances in use.

Evaluation and Findings

Design and Construction

As the baseline facility, it was necessary to gather and analyze some information and data "after the fact", meaning post construction/occupancy. This was the case with much of the design/construction cost and schedule information. This information was considered important to the overall study since future costs and timelines for the commissioned school would also be collected and reviewed as part of this study. This information will also be used to make comparisons to the commissioned facility in the final section of this report. Much of the historical data was provided by the district's Facilities Construction Department whose efforts at bringing this information together was timely and comprehensive.

As a restatement of the study methodology, this project was undertaken to compare two schools, one recently constructed and not commissioned, and one in the design phase and slated for commissioning. Therefore, any trends in cost or schedule variance must be taken in light of this fact. This study was not an attempt to gain voluminous historical data and perform a statistically significant analysis on multiple facilities within the school district. The following tabular data and narratives provide that background necessary for later discussion and comparisons with the commissioned facility.

Table 3. Baseline School – Design and Construction Costs

Expected Design Cost	$ 665,920
Actual Design Cost	$ 637,930
Expected Construction Cost	$ 10,400,000
Bid Construction Cost	$ 9,909,000
Actual Construction Cost	$ 10,030,080
Difference between Expected and Actual Design Cost	-4.2%
Difference between Expected and Bid Construction Cost	-4.7%
Difference between Bid and Actual Cost	1.2%

As shown in Table 3, the bid construction cost as well as the actual design cost was lower than expected with both percentages within nominal industry standards for estimating. This fact indicates that the district staff members as well as their design partners are keenly aware of cost estimating practices as well as costs associated with procurement of materials, hiring contractors, and prevailing wage costs. The variation between bid cost and actual cost is $121,080.00 and indicates a 1.2% difference. As with many construction projects, the building owner may adjust requirements during the process which may increase or decrease the contractors cost. Also, site conditions may vary from initially expected which can affect the contractor's expenses.

These conditions are accounted for through the change order process that is not unique to this or any new facility construction project. Since the initial objective of this study was to compare two facilities with respect to the mechanical, electrical, and plumbing (MEP) trades from the commissioning perspective, these change order items were investigated and cataloged accordingly. From the data collected, MEP change orders accounted for $94,973.00 of that difference or approximately 78% of the increased cost between bid and actual cost.

At this early stage of the study, team members were reassured that commissioning efforts focused on the MEP would bring the most benefit to the customer. Table 4 shows the change orders recorded for the baseline school and the associated costs for each item. Note that drainage, piping, irrigation and associated controls are considered MEP related items for the purpose of this study.

Table 4. Change Order Items and Cost – Baseline school

	Number of Change Orders	*Cost of Change Orders*
drainage in playground	4	$ 43,577
gym air conditioning	2	$ 24,322
misc PLUMBING	10	$ 11,099
misc ELECTRICAL	10	$ 4,820
misc HVAC	3	$ 3,693
plumbing/HVAC conflicts	1	$ 3,556
ventilation for electrical room	1	$ 2,497
misc FIRE/SECURITY	2	$ 1,409
pressure valve	1	$ -
weatherstripping on doors	1	$ -
library dehumidifier	2	$ -
TOTAL	**37**	**$ 94,973**

It should be mentioned that the change order to add air conditioning in the school gymnasium was a decision made on the part of school district administration to incorporate air conditioning in all new elementary school gymnasiums (policy change). This was done after the completion of the design process although the contracted architect/engineer (A/E) firm was aware of this possibility and accounted for future addition of a cooling coil in the gymnasium air handling unit. This fact did reduce some of the overall dollar impact of this change and showed foresight on the part of the District's Engineering Services Department and the A/E firm; although, from a construction standpoint, deletion of ventilation equipment, adding chiller capacity and associated design paperwork would have been accomplished more easily during the initial stages of design. As a further example of the impact that change orders can have on costs late in the construction phase, the table on the following page outlines the numerous steps involved in the addition of simple ventilation fan added to an electrical room. It was well documented in this case that 41% of these costs were associated with the change order process, while approximately $1,500.00 actually went to material acquisition. Although the dollars are relatively small in this example, it is easy to see how multiple instances might accumulate costs, and potentially affect project timeline as well.

Table 5. Example of Additional Tasks for Providing Ventilation as a Change Order

Prepare Opening in SR Ceiling	Sheet Metal Labor: Reassignment of Manpower
Touch up Painted Ceiling	Sheet Metal Labor: Concurrent Operations
Material Handling	Sheet Metal Labor: Beneficial Occupancy
Clean Up	Sheet Metal Labor: Site Access
PM Coordination Time	Coordination
Estimating Time	Drafting/As-Built Drawings
Field Clerk	Testing
As-built & Shop Drawings	Administrative fee

The larger change order amount for drainage was due in part to site conditions affecting plumbing and irrigation portions of the project as well as site drainage. As many in the design and construction industry realize, these problems are unavoidable in some instances, but in many cases can be alleviated with additional up front planning and oversight. It is expected that additional scrutiny provided by commissioning professionals will provide this added benefit. As indicated in Table 4 on the previous page, some items were recorded as no net cost increase due to offsetting factors as determined by the contractor and the owner's representative. This is sometimes the case where minor changes are accommodated by the contractor particularly if scheduling is not affected, and added design costs are not incurred. It may occur when upgrades to equipment are made in one area, while requirements in another area are relaxed or deleted.

Overall project scheduling and compliance with timelines was investigated and this data is shown in the accompanying figure below. As indicated in Figure 5, the gain in schedule attributed to design does not begin to offset the added construction days.

	Est.	*Act.*	*Diff*
Milestones:			
Design Begins *(Schematic Design Review)*		24-Jul-01	
Construction Begins *(First Construction Meeting)*	18-Mar-02	05-Mar-02	-13 days
Construction Ends *(Substantial Completion)*	14-Apr-03	31-Jul-03	108 days
Duration (days):			
Design Phase	237	224	-5.5 %
Construction Phase	405	513	26.7 %

Figure 5. Design and construction schedule results – Baseline School

Although construction time exceeded the expected duration by 100+ days, much of this was related to facility exterior concerns (drainage, irrigation, and other site conditions) and did not hinder the timely occupancy of the facility as indicated by the 31 July 2003 substantial completion date. School district policy is to ensure finished construction in advance of mid August school start date to allow for staff moves and facility preparation. It was observed by the study team during the facility walk through in late July that the majority of teachers and staff had ample time to prepare classrooms and common areas prior to the student's arrival. This is mentioned here with emphasis due to the extreme importance that the District places on adherence to construction schedules and timely project completion.

Throughout the construction process, clarification of existing design documents and specifications generate requests from contractors and subcontractors for owner and A/E clarification. This process, known as the Request for Information (RFI) process, can be an indicator of design clarity and completeness, level of communication between affected parties (owner, A/E, contractors), as well as overall attention to and importance of construction scheduling as held by these same affected parties. Again, since the focus of this study was concerned with MEP related commissioning and issues, the team gathered information on RFI's related specifically to these areas. For the baseline school, there were 22 total requests related to MEP design and construction. The average response time (turn around) back to the contractor was nine days.

This duration included initial meetings and discussion with final resolution coming either from the owner, the owner's representative, or a member of the A/E firm. Based on the size of the school, and in order to normalize results for future comparison, the study reduced the number of RFI's to 2.6 per 10,000 sqft of completed facility area. This will allow like data sets to be displayed for comparison in side by side detail with consistent units where inferences and potential impacts may be better described and understood.

As mentioned previously (see Methodology), the punch list is the result of an on-site inspection that includes both contractors and owner's representatives which takes place near the end of the construction phase. The numbers and types of items logged can vary greatly from project to project while the apparent reasons for listing are too many to detail here. Suffice to say that in general, the numbers and types of items can serve as an indicator of the contractor/subs attention to detail during the construction process, and may provide some indication of potential future problem areas in the facility. Table 6 provides a synopsis of these items. For reference to facility areas refer to Figure 2.

Table 6. Facility Punch list Items – Baseline School

	Above Ceiling Inspections		Final Punchlist	
	Total Issues	*Avg. Issues / Room*	*Total Issues*	*Avg. Issues / Room*
Building A	69	3.0	82	2.5
Building B	30	2.0	41	1.5
Building C	59	2.2	56	1.7
Building D	56	4.7	109	3.9
Mechanical Rooms	-	-	84	8.4
TOTAL	**214**	**2.6**	**372**	**2.8**
GRAND TOTAL	**586**	**2.7**		

Initial Observation/Walk-through

This portion of the study was unique to the baseline facility since the facility was substantially complete at the start of the commissioning study. Prior to initial occupancy, the study team (BESL and the commissioning agent) were provided the opportunity to perform a walk-through of the recently completed school. They were accompanied by various school district staff members, and in particular, the district Energy Manager.

From a design perspective, the facility was well constructed and showed much attention to detail from both the engineering and architectural standpoint. As with any structure, there are design and construction preferences which are unique to individual professionals and organizations. Some of these items have been formalized in the districts design guide. Therefore, the study team in making observations of the facility, tended to look past these areas and focus more on items which represented "improvements" in design and/or specific issues which should be addressed in any future construction and perhaps benefit from the commissioning process. This was not intended to be a "quality control" check of the engineering and design firm, the contractor, or the school district's Facilities Construction Department. The efforts of the study team was an earnest attempt at observing a recently constructed school in the district, familiarizing the team with the district's design standards, and receiving feedback from faculty and staff as to their overall satisfaction with the facility to date.

At the outset of the project, and once the baseline school had been identified, the study team began compiling an observation log. The final observation log contained 37 total items of which 23 items were attributed to the school walk through. The observations from the baseline school were subjectively categorized by the research team into Observation Only, Design/Construction Issue, Information Only, and Task. Many of the items logged required no follow up action on the part of the study team. For example, Information Only and Task items were merely recorded for the benefit of the team members. Some observations logged by the team were noted through conversation with staff members rather than being "observed" and referred to internal operations and procedures unique to the district. Much of this information provided valuable insight to the team for conducting the remainder of this study.

Table 7. Excerpt from Team Observation Log – Baseline School Walk Through

Observation	Type	Impact/Response/Action (as required)
No pulse initiator was installed on the facility electrical meter	Des/Cons Issue	Inability to track consumption accurately; required for trending; payment issues appeared to be the concern
Pumps on shock pads but couplings were rigid not flex type	Des/Cons Issue	Equipment vibration might cause leaks at joints; check design guide; update if necessary
Use of three way valves is prevalent at this location	Des/Cons Issue	Trend is to move away from three way valves; energy impacts; check design guide
Some AHU coils w/o construction filters appear dirty	Des/Cons Issue	Early M&O issue; can result in comfort calls; needs specific guidance and oversight
Several areas w/ complaints of noisy diffusers	Des/Cons Issue	Early M&O issue; verification of Test and Balance
Stagnant or no air in portions of library reported	Des/Cons Issue	Early M&O issue; above ceiling inspection and check Test and Balance report
OA sensor requires screening from insects	Des/Cons Issue	Staff reported mud wasps building nests; faulty OA temp; design guide note
Rotunda had adequate day lighting but lights remained on	Des/Cons Issue	Excess energy use; check design guide
Thermostat location was poor in some rooms	Des/Cons Issue	Early M&O issue; hot/cold calls; refer to design guide; some issues with placement of furniture items
Cooling coils/valves icing over	Des/Cons Issue	Early M&O issue; potential warranty or installation problem; notify maintenance

Table 7 indicates those items which the team considered as requiring some type of follow up, either with regards to design, procedures, or merely to determine the status of the item within the district. As indicated in the table, there appeared to be no major issues observed, but also noting that the school had not yet experienced its first year of occupancy. From a maintenance and operations standpoint, the first six months of occupancy are critical in any new facility and any equipment, installation, calibration, or design issues will normally surface during this “wring out” period.

It should be noted that observation of the baseline school was undertaken at the same time that the study team began gathering necessary information on other aspects related to design and construction of the facility (schedule, costs, change orders, RFI’s, etc.).

The photos in Figure 6 show some of the items mentioned above which made their way to the teams observation log during the initial facility walkthrough at the baseline elementary school.

Figure 6. Representative items noted during baseline school walkthrough

At this point the team also began laying the groundwork for collecting required utility data, warranty service information, and work order data for future long term analysis. This quantitative data was later supplemented with qualitative information in the form of questionnaires and interviews with various building occupants and school district staff members. These qualitative measures were valuable in gaining the occupants perspective of the buildings operation, and how well it met their particular needs.

Post Construction Occupancy

During initial occupancy of the facility by faculty and staff, discrepancies with the building and its operation were noted. The typical response of district staff is to log all trouble calls, initiate a maintenance work order (WO) indicating the appropriate trade/shop, and send technicians to the school to investigate the problem. Since the school is a new facility, some items are the responsibility of the building contractor or selected equipment vendors and covered under the warranty. Maintenance personnel along with the districts construction management inspectors confirm warranty issues and refer them as necessary for resolution. The district maintains concise records of warranty service requests, pending status, and completion. Items not classed as warranty remain in work order status to be completed by the appropriate district maintenance trade/shop. Work order requests can be actual staff requirements that were not included in the original design and construction documents. They may also be legitimate maintenance items that do not warrant contractor notification. Some of these items may in fact be the result of damage incidental to routine operations in the school or as a result of vandalism.

The study team obtained a log of all work orders for the baseline school about midway through the first year. This period was considered to be the most critical for facility operation. The work order log included 278 total entries. This works out to approximately 32 work orders per 10,000 sqft of occupied building area. The cost associated with the complete listing was approximately $33,000.00 broken out between material, $10,000.00 and labor at $23,000.00 (approx. 1400 man-hours). Focusing on MEP related issues, work orders in these areas were sorted from the composite list. Overall, there were 122 MEP related work orders/warranty items which resulted in a cost breakout of $1,600.00 for materials and approximately $7,500.00 for labor (400 man-hours). During the first six months of operation, MEP related work orders accounted for approximately 30% of the total cost and man-hours for the year. Table 8 below highlights work order areas and cost during those first six months of facility occupancy.

Table 8. MEP Related Work Orders – Baseline School

	Number of Work Orders	*Cost of Work Orders*
Routine Maintenance	65	$ 7,088
Preventive Maintenance	27	$ 898
Warranty Issues	18	$ -
Vandalism	5	$ 537
Contractor Support for Projects Not Initiated by Maintenance	5	$ 466
New Work	2	$ 60
TOTAL	**122**	**$ 9,049**

Specific work orders issued included addressing problems with leaking water (pipes, faucets, joints), operation of gym air conditioning, and faulty ballasts, many of which were reported by the building occupants. Miscellaneous items include work related to getting the school ready for initial occupancy and hot and cold calls reported throughout the observed time period.

Based on the area of the facility reported earlier, MEP related work orders averaged 14.1 per 10,000 sqft of building area. The study team continued to track work orders for the school throughout its first *full calendar year* of operation versus an average 9-10 month school year. It was decided that more benefit and supporting data would be gained if this was the benchmark for both schools in the study. Work orders for the remainder of the year thru August 2004 showed a decrease in MEP work orders processed while the overall number for all shops tended to decrease as well. Total work order request topped out at approximately 350 for the year which indicate a marked drop over those recorded during the first six months total. This total equates to approximately 41 work orders per 10,000 sqft for the first year of operation. This serves as a further indication that the majority of warranty and work order issues are "discovered" and reported during the early months of occupancy.

MEP related items trended downward to 4.5 per 10,000 sqft of facility area, the majority of these being either hot/cold calls or minor controls related issues. Of these total MEP related issues, an additional 10 were logged as warranty service issues bringing the total number of warranty related items to 28 for the year. It merits mention at this point that based on observation and reported data the district's maintenance staff is performing admirably at staying ahead of a multitude of issues before any crisis can emerge. Given the total number of work orders logged and the significant portion of MEP related items, it is assumed at this point that some of the warranty service issues as well as routine maintenance problems might have been avoided through implementation of the commissioning process. The table below indicates numbers for work order data for both the initial six month period and then the first full year of occupancy. Please note that warranty items are "rolled up" into the totals and are broken out in the table for later comparison and discussion. Also of note is that the school year ends in May, therefore the remaining year of data as indicated by the study represents the final 12 weeks prior to summer vacation for students and staff at the school as well as an additional 10-11 weeks where the school is largely unoccupied. This would generally account for the overall lower numbers of work orders (see Table 9) added during the remainder of the year at the facility.

Table 9. Work Order Totals/Trends – Baseline School

	at 6 mos	per 10ksf	at 1 year	per 10ksf
Number of WO's	278	32.3	350	40.7
MEP Work Orders	122	14.1	161	18.7
Warranty Items*	18	2.1	28	3.3

* Warranty items included in totals

Energy Consumption

An important area of observation and one which was of particular interest to all parties involved in the study was the potential impact of commissioning on utility costs and energy consuming equipment and components. This was in fact one of the crucial areas for determining whether there might be any "quantitative" benefit from the commissioning process as a result of this study.

Utility bills for electric and natural gas consumption for the baseline school were obtained from the school district's energy management staff. Energy use data was provided by the district in two formats. Summary data for electric and gas utilities provided monthly totals for kWh, demand, and ccf along with the costs associated with these amounts. Interval data (15 minute) for electrical energy consumption for each month of the study was also provided for input into simulations as well as for further spreadsheet analysis. Along with this information the team obtained information about the districts average energy use for all the elementary schools in the district. At the time of this analysis, there were a total of 51 elementary schools used in the determination of district-wide energy consumption which was based on the total number of schools, energy consumed at these schools, and conditioned floor area for these facilities.

Based on the data analyzed, the average monthly energy use for all elementary schools in the district is approximately 3.9 kBtu/sqft combining both electricity and natural gas. The most recent Commercial Building Energy Consumption Survey (CBECS) for 2003 provides data for selected facilities by region. For educational facilities in the south, the average energy is calculated to be approximately 6.0 kBtu/sqft. This amount shows a slight increase from the previous amount of 5.7 kBtu/sqft reported in the 1999 survey. Observation of information provided in the survey indicates a larger proportion of data for the southern US region as opposed to other regions taken individually. Increase in average energy is most probably linked to the addition of approximately 35,000 buildings in the southern region over the 1999 to 2003 period which accounted for an additional 1,635 Msqft in the educational area. The figure below indicates energy consumption for the baseline school during its first year of operation. For comparison, the CBECS average is shown as a benchmark along with the district average for all elementary schools as computed from data provided to the study team.

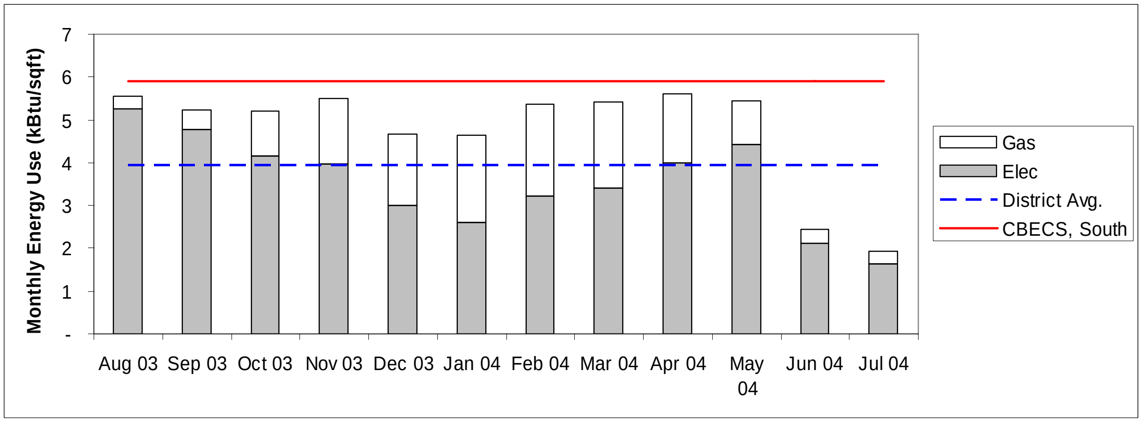


Figure 7. First Year Energy Consumption Statistics – Baseline School

The average monthly energy use for the baseline school is estimated at 4.7 kBtu/sqft which breaks out into 3.5kBtu/sqft for electricity and 1.2 kBtu/sqft for natural gas. Overall monthly expenditures for energy averaged approximately $0.08/sqft for a total average cost of $6,559.00 per month. Although these values are higher than the average reported for the district, some variation may be attributed to the fact that this school is one of the first facilities to include an air conditioned gymnasium.

Based on the volume of conditioned air required to satisfy this space cooling requirement some increase in energy costs per area are expected. Another trend noted is that new school floor plan area is increasing. The baseline facility was roughly 6,600 square feet larger in floor area that the average elementary school in the district. This data is provided for informational purposes only since state and nationwide trends in this area are not provided in this report.

Building Simulation

In order to provide a more detailed analysis and understanding of energy consumption in the baseline facility, building energy simulation models were constructed. A detailed discussion of simulation, model calibration techniques, normalization of selected parameters, and building coordinate transformation are beyond the scope of this report, but some aspects will be described in order to familiarize the reader with the process undertaken. These explanations will be provided in appropriate areas, generally associated with a given figure for clarification. The background work accomplished for this study will also be briefly explained in order to provide a rudimentary understanding of the process and the level of complexity undertaken by the study team.

As an introduction to the reader, a building energy model should mimic the actual operational characteristics of a given facility. It will provide some numerical output concerning the expected energy expenses for that building. If the model is exacting enough in its calculations, and the input data is correct, or as close as possible with respect to actual conditions, then simulated output will closely track actual utility expenses for the building. A typical building simulation takes into account the following input parameters:

1. Building area, orientation
2. External and internal walls and construction materials (e.g. doors, windows, roofing)
3. Specific engineering properties of these materials (e.g. conductivity, reflectance)
4. Heating and cooling equipment in the building (numbers and type)
5. Operational characteristics of heating /cooling equipment
6. Lighting within the building (numbers and type)
7. Additional energy consuming equipment in the building (e.g. appliances, computers)
8. Building occupancy and scheduling (number of people, hours of operation)
9. Energy management protocols (e.g. on/off scheduling, temperature setback)
10. Cost of energy from the utility provider (e.g. electricity, natural gas, other)
11. Local weather conditions

Many of the input parameters listed above must be properly linked to other components for the simulation to “run” as intended. As with any computer programming task, if these are improperly mapped into the program an error will occur during program runtime and the operator will then be required to debug the program code. For example, walls must be properly joined and adjacent coordinate locations must correspond to the next structural element.

A simple example of this is shown in the line diagram on the following page. While inputting dimensions and structural member location and orientation into the model, it is necessary to consider all previous sections of the building already entered into the model. This is due to the fact that there is a single reference point for the facility coordinate system.

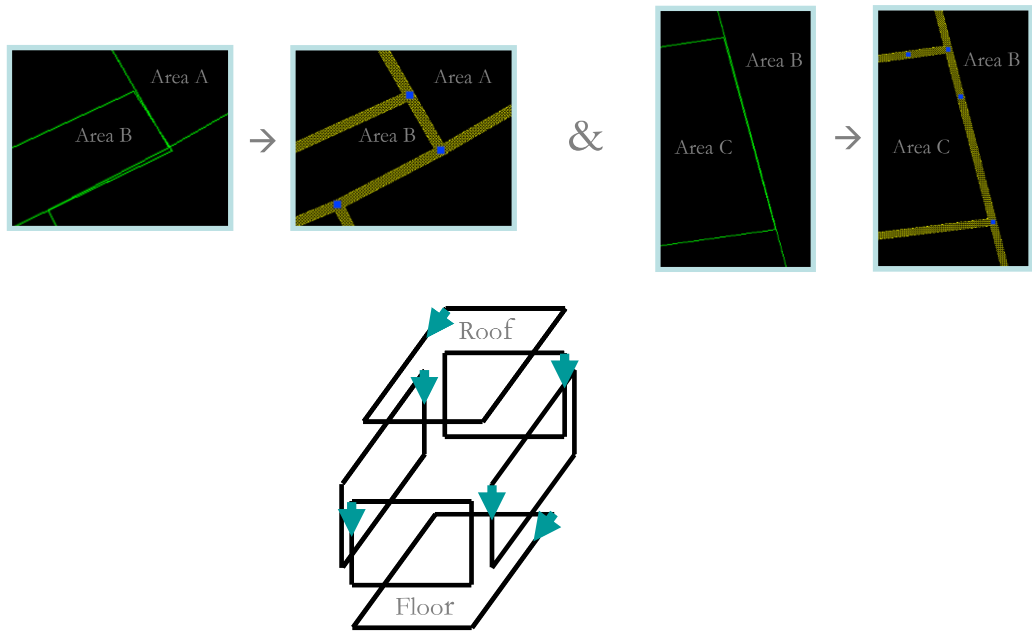


Figure 8. Frame of Reference and Coordinate Application During Simulation Input

Figure 8 directly above indicates some of the issues that might possibly arise without due diligence at the outset of the modeling process. This attention to detail is equally important when simulating existing equipment and other building characteristics that will be addressed later. The figure above is meant to show that points within adjacent walls must share common reference points if they are to adequately and correctly represent the building envelope.

Algebraic algorithms along with trigonometric transformations are used to render the structural members of the facility as a complete building system. This attention to detail although not extremely difficult is tedious and time consuming. It is however a necessary task if the model is to simulate and render the facility as a connected envelope without air gaps and/or incomplete interior and exterior partitions and walls. Without these efforts, the simulation may "assume" that particular adjacent zones within a building are "connected airspace" or that incomplete exterior walls are subject to infiltration from outside air climatic conditions. The net effect would be that overall energy use calculations and resultant output for the entire model could be rendered invalid. Since the point of reference for the entire building is fixed inside the simulation, it is necessary to use this single reference when moving the facility from the design drawing to the working model.

Basic elements of this transformation are shown on the following page to provide a snapshot of the detail undertaken in this process. Narrative explanations will be minimal, with emphasis placed on the end result of providing a complete, simulated representation of the building.

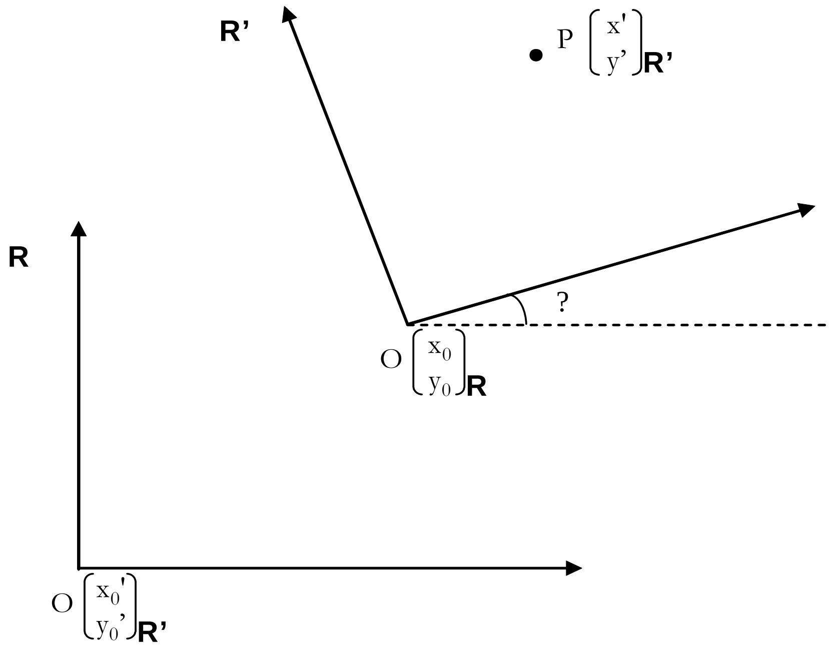


Figure 9. Coordinate transformation scheme for building envelope model

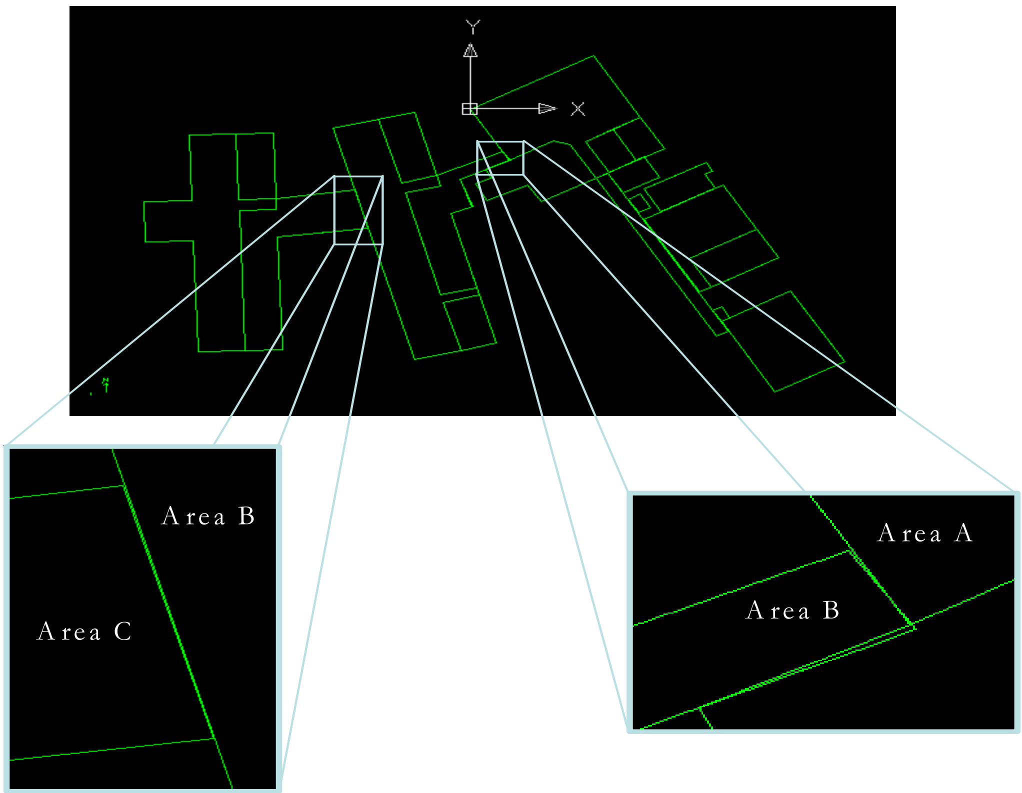


Figure 10. Initial 2D layout of building floor plan prior to applying correction

The necessity for coordinate transformation is apparent as we view the initial two dimensional representation of the facility shown in Figure 10 on the previous page. It becomes more critical as we proceed through the process to complete facility input in the simulation program for the entire three dimensional model taking into account separate wall planes. Each section of the facility taken off the architectural drawing had to be “located” in the simulation based on its distance and angular orientation from the specified point of reference. This entire effort is necessary to generate the wire frame facility model, shown below, which is used to evaluate weather effects such as shading, direct and indirect sunlight, prevailing wind and wind film effect, conductance through windows and doors, etc. as well as the affects of adjacent cooling heating zones, and other computed values used in deriving overall energy consumption for the facility.

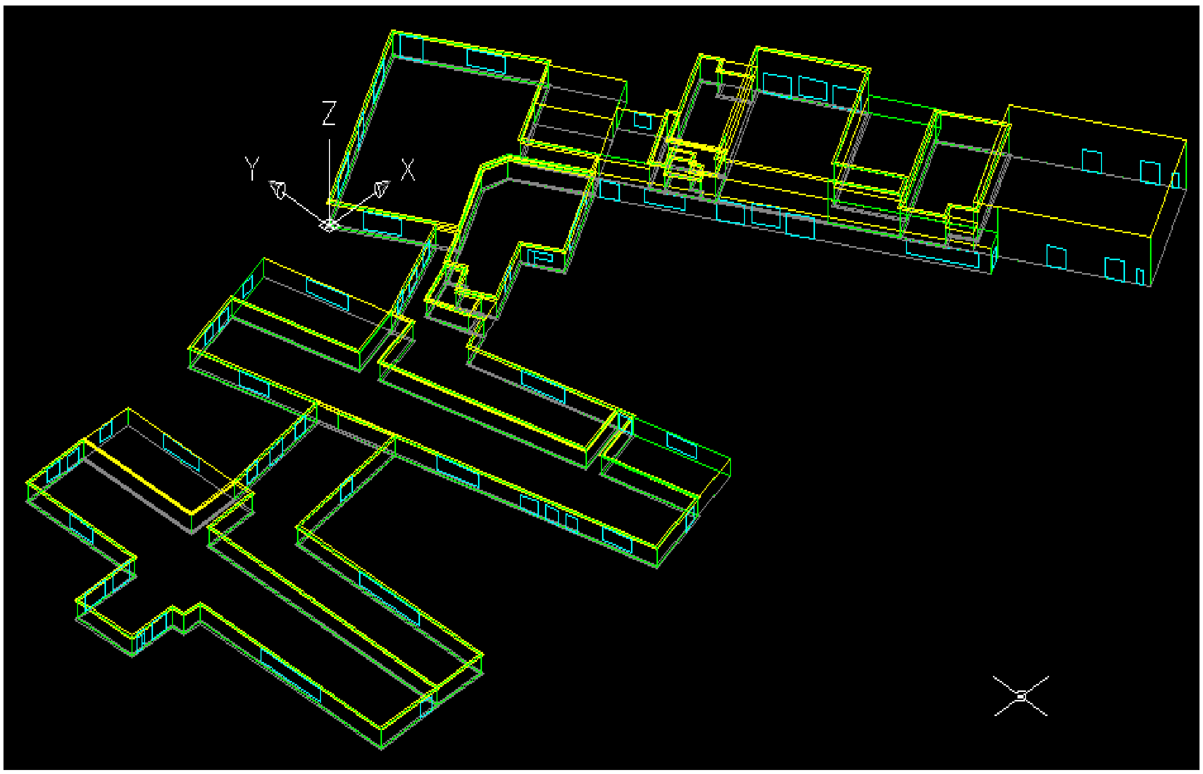


Figure 11. Building footprint and structure as generated by EnergyPlus

As mentioned in the section on Methodology, Air Model was initially used to determine if all inputs were accounted for and to get a feel for output values to determine if they were in the “ballpark”. This approach was taken since the follow up (EnergyPlus) simulation model was much more rigorous and much less forgiving in finding and fixing errors in the computer code. Much of the information input into the facility model with respect to cooling and heating equipment was obtained from the energy management and control system (EMCS) for the baseline facility. Equipment type, quantity and location were cross referenced with as-built drawings to ensure accuracy. This was also verified during site visits made to the facility.

Sequence of operation, scheduling, on/off and setback was primarily from the EMCS computer screen shots.

A typical example of a screen shot used for defining and initializing input parameters is shown in the figure below.

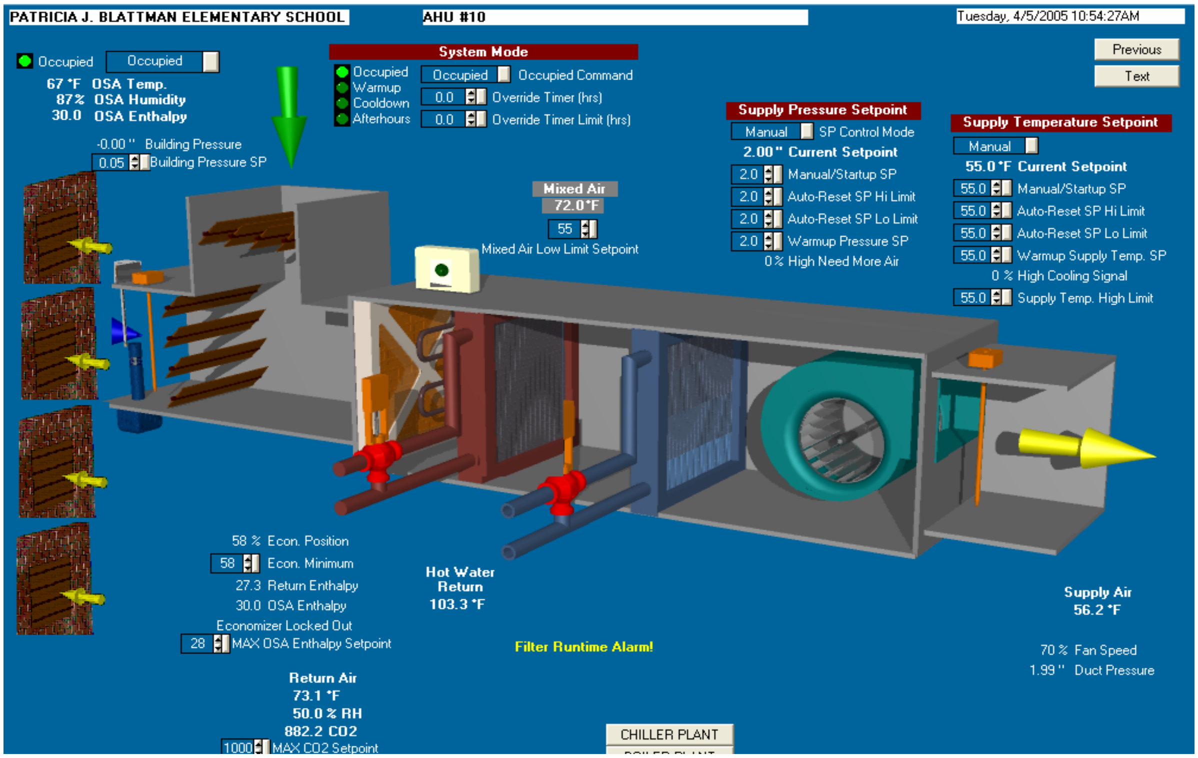


Figure 12. Representative Air Handling Unit (AHU) as Depicted on EMCS computer

Personnel in the district's controls shop and EMCS office were invaluable in assisting the study team in gathering the required data for input into the simulation. Equipment function was checked on numerous occasions in response to input variation. This further allowed the simulation model to be verified on a zone by zone basis with respect to equipment sequence of operation. The simplified schematic in Figure 13 below might represent an individual AHU shown in Figure 12 above.

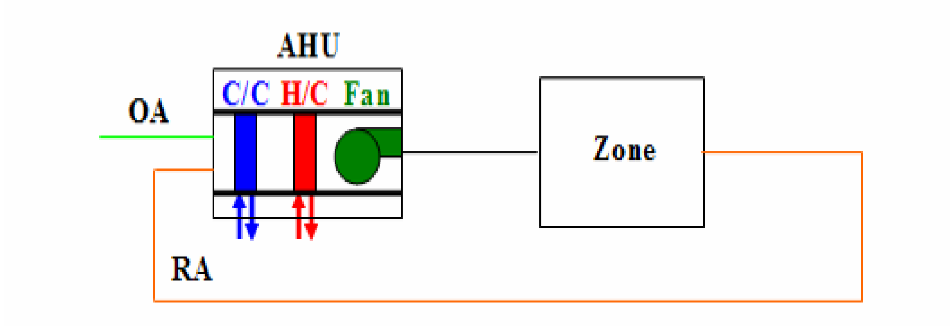


Figure 13. Simplified AHU schematic – Baseline School

As in the case of the building envelope, there is much more detail that needs to be applied before the model can mimic correct operation of the facility and its installed equipment. The simplified schematic shown previously becomes much more complicated as it is translated into piping, air flows, pumps, chillers, boilers, terminal units, temperature sensors, and other associated equipment items necessary for the simulation program to recognize and digest. A nodal diagram is shown below in Figure 14 which is more representative of what the computer simulation uses when determining energy use for a given zone. Multiply this by the number of zones within the building and include individual equipment parameters and sequence of operation and it becomes apparent that the input process leading up to the actual simulation is extensive.

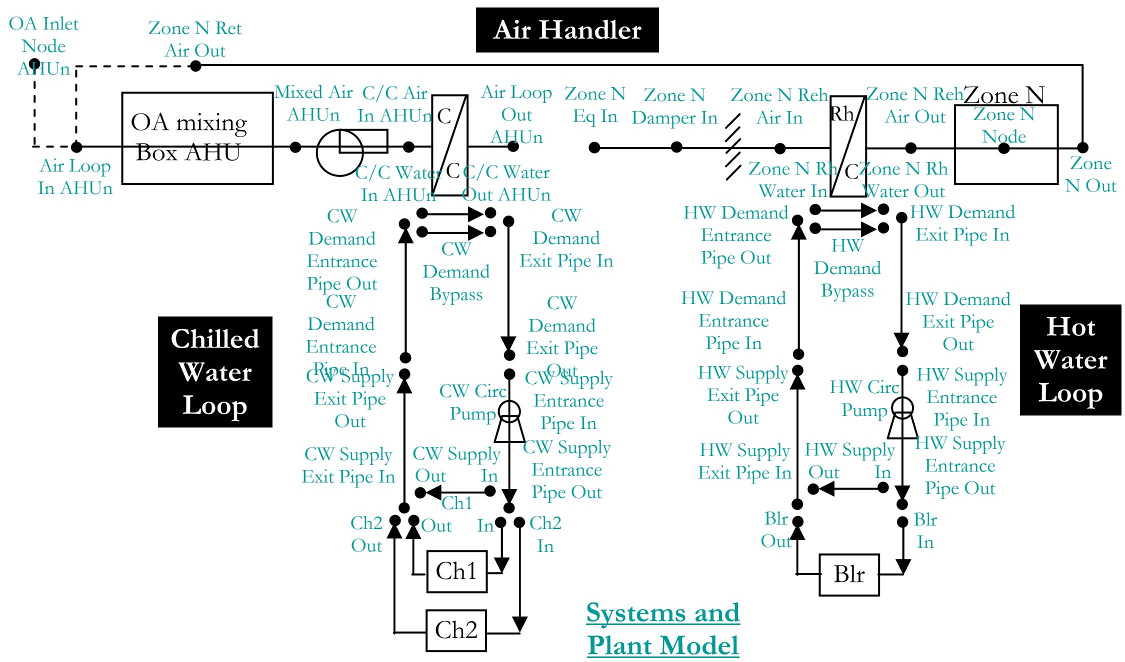


Figure 14. Nodal representation of AHU and associated equipment for simulation

Equipment responsibilities must be determined by zone. Adjacent zones may or may not have an energy related impact on each other and is dependent on internal structural conditions such as walls, partitions, glass, and hallways. Internal loads such as equipment in the school kitchen are factored into the model both from a plug load standpoint as well as from a possible heat gain perspective. Lighting, computers, and other equipment found in the facility are representative of those inputs required for the model to be effective at simulating the actual building. From a standpoint of latent and sensible heat gain, the personnel and student load assigned to the building are required as part of the occupancy and facility schedule portion of the modeling program. Numerous simulation runs were accomplished to verify occupancy schedules, equipment operation, as well as base load energy consumption. This base load, typically considered plug load plus lighting was shown to be temperature independent and therefore not associated with HVAC equipment operation.

Figure 15 indicates the amount of energy attributed to this base load and how it relates to overall energy consumption within the building. This was useful in that the simulated facility would be expected to indicate this same level of consumption for these same devices and loads.

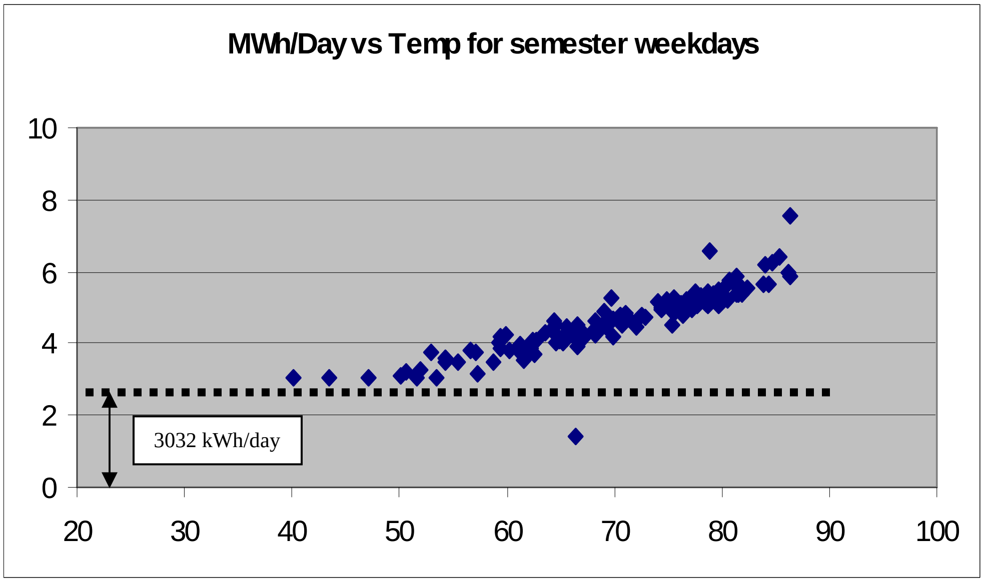


Figure 15. Baseline school measured data indicating facility base load during occupancy

Figure 16 indicates the total building footprint as well as zoning requirements for the facility. Each area was modeled based on the system serving that particular area.

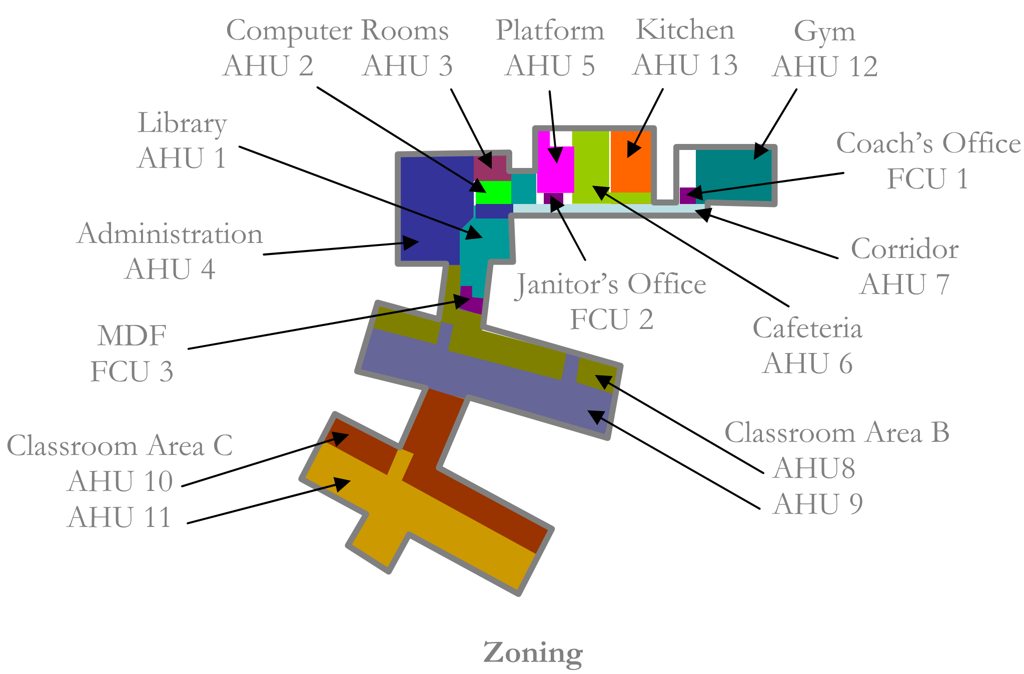


Figure 16. Building area layout with associated major equipment items

This detail is mentioned to indicate that every aspect of facility operation was important to the modeler in order to accurately account for energy utilization. Recall that in the computer simulation, adjacent occupied zones may impact equipment operation, and comfort levels which in turn increases or decreases energy utilization for that area. As we proceed toward completion of the model, it becomes apparent that the integration of cooling/heating equipment, auxiliary energy consuming equipment, occupancy, scheduling, and building envelope combine together to replicate the actual operation and energy consumption trends of the facility.

Since this school was already constructed, utility bills provided by the district were considered as the actual measured value for energy consumption in the facility. The "bottom line" expectation is that the final simulation closely tracks measured input data. Exact duplication of values is not expected, while proximate values within certain tolerances should be the outcome. Also, the overall trend (slope) of the simulation should approximate that of the measured data as well. As indicated on the plot, the calibration signature is considered a measure of how well the simulated data tracks the measured data on a point by point basis. For the majority of data points indicated the building simulated performance closely approximates actual performance and therefore will be considered useful in conducting further investigation of facility energy costs and equipment and construction options.

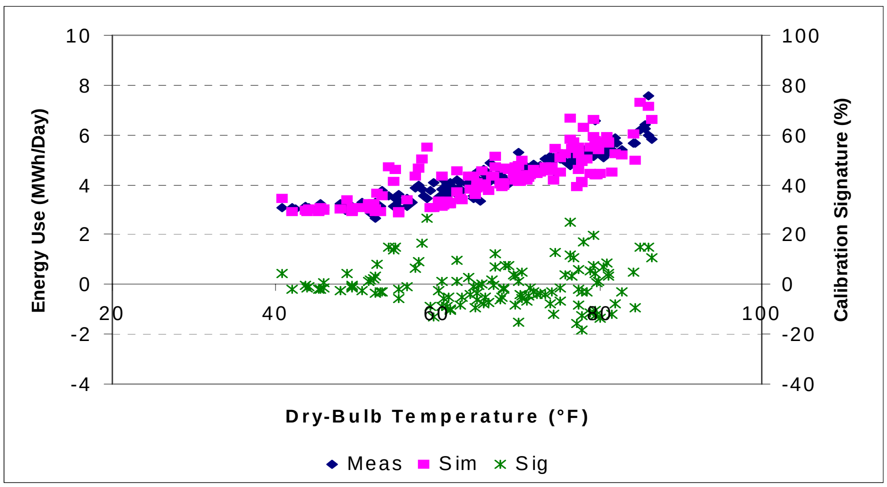


Figure 17. Simulated versus measured data as a function of outside air temperature

Since the baseline building did not have the benefit of the commissioning process, it was hoped that through development of an accurate model, equipment changes and building enhancements could be adjusted within the model to gauge their impact on energy consumption. This would be performed from a hypothetical standpoint in order to bolster the case for commissioning. If any or all of these "changes" showed reduced energy consumption and could be linked to this simulated, commissioned facility, it might provide significant incentive to adopt the measure in future construction. It would also provide added incentive to consider commissioning as an integral part of new school construction in the future. This supplemental simulation process was accomplished near the end of the study with significant input from school district engineering and M&O staff members. Results of these additional simulations for the baseline school are addressed in the final section of this report.

Commissioned Building – Krueger Elementary School

Since the facility being addressed in this section of the report was under design at the outset of the study, it is reasonable to include background on the school district's capabilities, and building design/construction process. This is done prior to providing a building description and evaluation of the facility as in the case of the baseline school. This information is presented in expectation of being thorough in delivering needed background for the study as well as allowing the reader to draw comparisons with other school organizational structures that may be encountered.

Building Construction Process

Through observation of the commissioning process, the team was able to get a sense for the standard practice for constructing facilities within the school district. These observations, along with ongoing data collection for the baseline school (e.g., plans, change orders, punch list…) allowed a better understanding of the roles and responsibilities of departments and the steps undertaken by the district for new school construction.

Due to the large size of the district, the Facilities and Operations Division (headed by the Assistant Superintendent) is a substantial organizational element consisting of three departments: Engineering Services, Facilities Construction, and Maintenance and Operations (M&O). Energy Management staff report directly to the Assistant Superintendent as a separate branch of the division. Staff members from all four areas are routinely engaged in all phases of the design and construction process to varying degrees. The typical role of each entity in the process of design/construction with respect to new facilities is listed below:

- *Engineering Services*: update and publish the district's Facilities Systems Design Guide, evaluate new technologies, conduct trials of new technologies, specify sequences of operations
- *Facilities Construction:* update and publish the programmatic design guides, manage the design process, provide construction management function
- *Maintenance and Operations:* provide input into facility design process, trade-specific supervision of maintenance staff, manage work-orders/warranty issues, oversee Energy Management Control System (EMCS)
- *Energy Management:* engage with other departments to improve energy performance of facilities, implement scheduling of facilities, and evaluate energy efficiency technologies.

The following paragraphs provide only a brief outline of the process undertaken during new school construction. There are in fact many details, procedures, transmittals, and contractual stages that are key to the process as well. These details are not considered relevant to this discussion as the main objective is to acquaint the reader with the more general aspects of the design/construction process as it occurs and also some potential pitfalls that are frequently encountered.

Design Guides

This school district maintains a very detailed set of documents that comprise the design guide and serves as the master specification for any new construction project. As expected, staffs from different departments have varying opinions on the appropriate level of specificity to be provided in this guide. The district attempts to generate a balance between providing enough specificity to ensure consistency across schools, to ensure and facilitate maintainable buildings, while at the same time providing enough latitude to designers to develop the best solutions for the given requirement. The design guide is periodically updated with input from a range of stakeholders, although the district admits that the guide is at times out of date in certain areas. The design guide recently underwent a complete revision, but some or all of the changes were not applied to this design due to timing constraints. It is expected that the results of this study may provide future input to the districts design guide.

Pre-Design Phase

The district planners make the determination as to where new schools are to be built, and the number of students to be accommodated there. Because of the dramatic growth in population in this part of the city, it is not uncommon for schools that are only 1-2 years old to be supplied with portable classrooms. Accommodation is made in the site layout for adding these portables. The design guide provides most of the information needed for programming of a new school, although a particular school may have its own requirements, such as the number of special education classrooms or computer labs, or the library facilities. In addition, the district has evolving requirements such as increasing needs for security lighting, or a policy to provide air-conditioned gymnasiums. These considerations are generally made in the early planning stages and communicated to the designers (A/E firm). A review of the 35% Schematic Design which includes many of these special considerations, political concerns, site plans, color schemes, and architectural rendering is held with the design team, the owner's representatives, and the Board of Trustees. Discussion and compromise about the conceptual design is expected to yield Board approval at this stage.

Design Phase

During the design phase, there is periodic interaction between the design team and the owner's construction staff. A design review is held at the 65% design complete stage. Although the district has clear requirements as to the level of documentation expected at this stage, it is common that MEP design will lag the architectural design. The fact is that engineering designers are hesitant to put much time into component details when major elements of the architectural design may be in flux. For example, preliminary load calculations and structural connections done at this point would have to be re-evaluated based on architectural changes, and mechanical piping and ductwork generally follows architectural layout. This design review is typically attended by representatives of each of the design disciplines, and by representatives of all four Facilities and Operations areas. At this meeting, the 65% drawings are laid out on a table and the designer presents the key elements of the design. All affected owner's representatives view the plans and hear the presentation and make comments.

The logistics of this type of review (i.e., inability of more than one or two people to view the drawings at a time) can make the review somewhat difficult. Also, based on the statement above that some areas of the design may be lagging other areas does not afford all affected parties the same level of detail for viewing. The 95% design review is considered as a substantially complete design and intended to intercept and alleviate major integration oversights. However, in many instances it is actually the first opportunity for review of the detailed MEP designs. The project bid date is set in advance of the completion of the design and is geared to strict timelines adhered to by the school district which is based on facility need dates. This may place pressure on the reviewers knowing that they are faced with this constraint and in some cases an incomplete review is the result. Another potential problem arises when the plans are issued regardless of the status of any review comments, which may result in the issuance of an addendum shortly after the release of the design.

Construction Phase

The director of the Facilities Construction department serves as the overall Construction Manager for the project, and construction inspectors within that department provide much of the day-to-day oversight of the project. While the district does not have a commissioning process currently in place, the general perception is that they get the most out of the contractors due to their large size (numbers of schools and projects) and the contractors' desire for future projects with the district. During the construction process, there are key times when the Maintenance Managers (M&O branch) are invited to tour the site to provide necessary feedback on the facility and to observe equipment locations and routing prior to ceiling installation. Unfortunately, observation on this project has shown that the process has not worked as well as intended. The tours are sometimes scheduled at the last minute with maintenance staff receiving insufficient notification. Due to this fact, staff is not always available, and valuable comments and observation are missed. Bi-weekly construction meetings are held with key contractors and owners representatives, and very clear logs are maintained of requests for clarification, requests for information, proposed and accepted change orders.

Completion Phase

The design guide/specification includes some criteria for accomplishment during the project completion phase, but they are not located in a single section of the spec, and the process for evaluating them and identifying follow up actions if criteria are not met is unclear. O&M manuals are routinely distributed by the contractor or equipment vendors, although the spec does not include requirements for what is to be included, and often these packages are not consistent from project to project. Facility/equipment training is also somewhat ad hoc: the requirements for training are not made clearly and in sufficient detail in the spec. At the conclusion of this phase, detailed site inspections generate punch lists very near the end of the project when some contractor subs may no longer be on site.

Occupancy Phase

After substantial completion, the school staff typically occupies the building shortly before the start of the school year. At this point, M&O staff maintains a make-ready list for the facility and support teacher and staff activities to get the building ready for students. Significant focus is put on the school dedication, approximately three months into the first year of occupancy, and all departments engage in activities to ensure that the building is "operating smoothly" on that day. The M&O department has a Computerized Maintenance Management System, and all work orders are issued through that system and logged. Warranty service issues which require contractor or equipment vendor call back is tracked meticulously as this may entail significant labor expenses and affect high dollar equipment items. The district has in the past held post-occupancy evaluations and lessons learned workshops, although now that the pace of new school construction has picked up, this is a less common practice.

Facility Description

A description of the facility and its installed systems and components will be limited to those equipment items of interest under the commissioning process. Complete operational details and are not provided for equipment and systems as part of this report. This is in keeping with the information provided for the baseline school, as a rudimentary idea of the facility is addressed to provide background as to the project and acquaint the reader with basic details for future reference.

The commissioned school is single storey, multi-wing facility belonging to Northside Independent School District located in San Antonio, Texas. A footprint of the general layout of the facility is shown in the figure below.

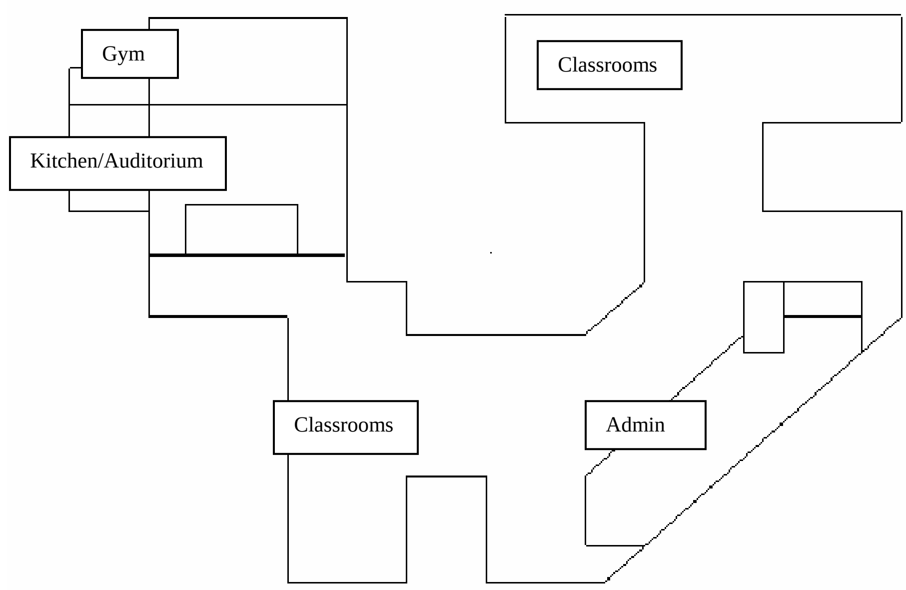


Figure 18. Commissioned school footprint – Dean Krueger Elementary School

This structure houses those functions typically found in any modern elementary school, e.g., classrooms, library, administrative offices, cafeteria, auditorium, and gymnasium. The area of this facility is approximately 100,800 gross square feet with all areas being considered as conditioned space. Environmental comfort is provided by two packaged, air cooled chillers rated at a nominal 169 tons each. Smaller package cooling units (rooftop or pad mount) are also present to satisfy specific zones within the building. These cooling units are coupled with selected AHU's or fan coil units to provide conditioned air to specified areas of the building. A total of fourteen air handling units (AHU) provide conditioned air to numerous variable air volume/fan powered terminal units throughout the school. A separate dehumidification unit is provided for the school library. Six AHU's are equipped with variable speed drives to reduce fan speed and conserve energy when cooling/heating set points are satisfied. Facility heating is accomplished by means of a single boiler rated at a nominal 2678 MBH output, which provides hot water to AHU heating coils as well as selected zone terminal units within the building. Duty cycling of major components and system scheduling (set point, on/off, setback) is controlled by the districts energy management and control system (EMCS). As in the baseline facility, the majority of light fixtures inside the building are recessed grid or surface mount, F32-T8 fixtures with 2, 3, or 4 bulbs depending on application. High pressure sodium and metal halide fixtures round out the remainder of lighting components installed at the school. The architect for this facility was the same designer as the baseline building and once again made ample use of day lighting in areas where applicable such as classrooms, entryways, and vestibules. As expected, a large plug load is evident in the kitchen area due to the significant number of appliances in use. Examples of the types of equipment installed in elementary school kitchens include 60 quart blender, hot food wells, ice makers, convection ovens, refrigerators and freezers, combination oven, food disposer and dishwasher. This affects energy consumption directly through use, but also affects building environmental systems which must maintain comfort in this area.

Evaluation and Findings

Design and Construction

The study team as well as the commissioning authority (CxA) had the opportunity to monitor the some of the design phase as well as the entire construction phase of this project. Previously discussed in the report is the fact that this school was already in the design phase when selected for the study. Ideally, the CxA would be involved from the outset of the project, and provide input in planning as well as design. The CxA would be responsible for assuring that the owners design was properly formalized and that it was met by all interested parties. As mentioned in the section on Methodology, the selection of this facility as the candidate for commissioning was due to the fact that it was "next in the construction queue". The choice was made to use the "Braun Road School", as it was originally called, to keep the overall study timeline within reasonable limits. Expected duration of the study based on estimated schedules was approximately three years.

The remainder of this section will provide data and information concerning the commissioned school, and will closely follow the format for the baseline school. Comparisons and conclusions as well as commissioning specific aspects for this school will be addressed in the final section of the report reserved for Findings.

Since significant background and detail was provided for much of the information presented in this section (see Baseline School), restatement of large portions of that narrative will not be undertaken for the sake of brevity.

Once again, this project was undertaken to compare two schools, one recently constructed and not commissioned, and one in the design phase and slated for commissioning. Therefore, any trends in cost or schedule variance must be taken in light of this fact. This study was not an attempt to gain voluminous historical data and perform a statistically significant analysis on multiple facilities within the school district. The following tabular data and narratives provide that background necessary for later discussion and comparisons with the commissioned facility.

The table below shows anticipated (budgeted) costs for the commissioned school as well as final costs as reported by the school district. Unlike the previous information for the baseline facility, additional discussion of the circumstances surrounding increased costs requires clarification at this point.

Table 10. Commissioned School – Design and Construction Costs

Expected Design Cost	$ 731,000
Actual Design Cost	$ 782,725
Expected Construction Cost	$ 11,200,000
Bid Construction Cost	$ 11,885,000
Actual Construction Cost	$ 12,290,214
Difference between Expected and Actual Design Cost	7.1%
Difference between Expected and Bid Construction Cost	6.1%
Difference between Bid and Actual Cost	3.4%

In those areas indicated and tracked in the study, initial cost relative to final expenses showed an overall increase for both the design and construction phases. As mentioned earlier in the report, it is often times the case that owner's requirements change throughout design and construction. Also, we cannot ignore the ever present chance of unexpected site conditions which may increase contractor costs based on these contingencies. For the commissioned facility, two distinct change orders are considered significant contributors with respect to project cost.

The school district, cognizant of changes in demographics, decided to increase the size of the facility to meet anticipated demand in the immediate area. This is readily apparent as the size of the commissioned school exceeds the baseline facility by roughly 14,000 square feet. This increase to add classroom space under Change Order #1 affected both construction and design costs. Therefore, information is presented to indicate the difference less this change.

Further explanation is required regarding the next line item in the table. During the construction process, significant weather delays were encountered by the contractor. These delays actually exceeded that number anticipated in the original contract document. Inclement weather affected site conditions, and led to unexpected problems with potential impact on overall project completion. At this point in the construction process, the district was faced with the dilemma of how to overcome this situation. The choice was to accelerate the remaining work and compensate the contractor for necessary increases in additional labor and man hours. The cost of Change Order #4 was an increase of approximately $200,000.00 over initial bid price. Table 10a on the following page reflects this information detailed above.

Table 10a. Commissioned School – Adjusted Cost Variance

Difference between Bid and Actual Cost w/o CO #1	2.0%
Difference between Bid and Actual Cost w/o CO #4	1.7%
Difference between Bid and Actual Cost w/o CO #1, #4	0.4%

The line reflecting a 1.7% difference reflects cost w/o this change order. Finally, cost variance is shown less both of these major change order expenditures. For both change orders (#1, #4) the MEP portion was approximately $160,000.00 or 44% of the total cost. The table below shows the break out of cost for these changes for MEP trades.

Table 11. MEP Cost Breakout for Change Orders #1 and #4 – Commissioned School

	HVAC	*Plumbing*	*Electrical*	*Misc.*
Change Order #1 - Add Classroom	$8,967.00	$8,280.00	$1,742.00	$305.00
Change Order # 4 - Accelerate Schedule	$56,327.00	$8,565.20	$75,711.64	
Total of Major Change Orders for MEP	**$65,294.00**	**$16,845.20**	**$77,453.64**	**$305.00**

Changes during the construction process as initiated by the owner, the A/E, or the contractor as a result of the RFI process were addressed through Contingency Change Orders (CCO) paid to the contractor. (These changes are generally smaller in scope that those mentioned above.) Proposal Requests (PR) were made on individual items and then rolled into a CCO paid by the district from contingency funds reserved for each major construction project. There were a total of 12 CCO's issued for this project. Under each change separate items were broken out by trade, and MEP related changes are indicated in the table below.

Table 12. Contingency Change Orders and Cost – Commissioned School

	Number of Change Orders	*Cost of Change Orders*
drainage in courtyard	1	$ 1,638
gym lighting retrofit	1	$ 19,368
misc PLUMBING	3	$ 3,222
misc ELECTRICAL	8	$ 5,041
HVAC ECM motors	1	$ 20,051
TOTAL	**14**	**$ 49,320**

A major change to the project, and one that will be addressed in greater detail in the final section of this report was the result of motor change out in terminal units throughout the school. This change can be directly attributed to input from the commissioning process and has quantifiable results affecting energy use in the building.

Overall project scheduling and compliance with timelines was investigated and this data is shown in the accompanying figure below. As indicated by the data, both design and construction exceeded anticipated timelines by slight margins. Based on the fact that there was a change in facility design with the addition of classroom area, an increase in both design and construction timelines is expected. Since weather delays are typically non-construction days, such increases can also be expected to lengthen the period of construction. Also, if site conditions are poor, site work, exterior trades work, and interior equipment deliveries are all hindered as a result.

	Est.	*Act.*	*Diff*
Milestones:			
Design Begins *(Schematic Design Review)*	22-May-03	01-Jun-03	
Construction Begins *(First Construction Meeting)*	23-Mar-04	07-May-04	45 days
Construction Ends *(Substantial Completion)*	01-Jul-05	20-Aug-05	50 days
Duration (days):			
Design Phase	306	341	11.4 %
Construction Phase	420	470	11.9 %

Figure 19. Design and Construction Schedule Results – Commissioned School

Although substantial completion is reported as 20 August, the school district took beneficial occupancy prior to the beginning of the school year in time for teachers and staff to prepare for student arrival. This timing (July 2005) was as originally intended by the district, with the exception that the accelerated schedule was paid for at the expense of a significant change order to the contractor. The photos below are evidence of the need for this accelerated effort, which proved to be the "best and only" option available under the circumstances. Photos were taken less than two months prior to beneficial occupancy by the district, and indicate the exhaustive level of effort required by district staff, contractors, designers, and commissioning personnel to ensure timely completion of the facility.

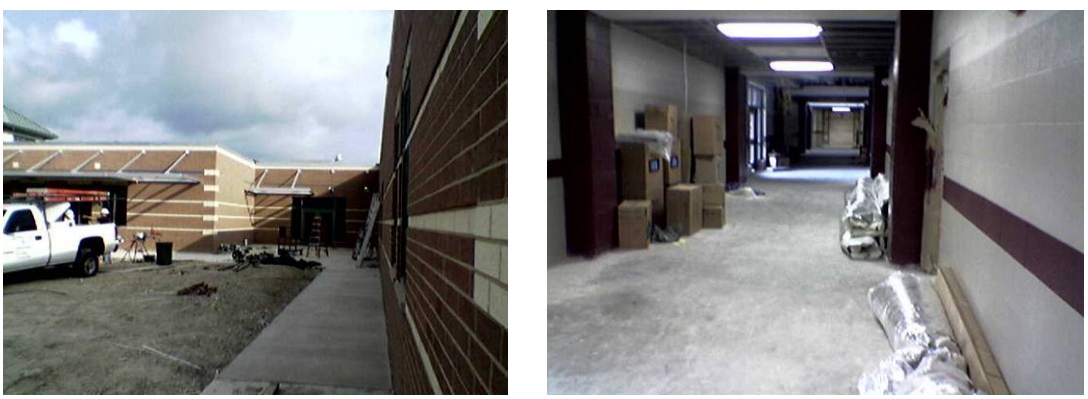


Figure 20. Facility exterior and interior under construction – Commissioned School

As mentioned previously (see Methodology), the punch list is the result of an on-site inspection that includes both contractors and owner's representatives which take place near the end of the construction phase. The numbers and types of items logged can vary greatly from project to project while the apparent reasons for listing are too many to detail here. However, the numbers and types of items can serve as an indicator of the contractor/subs attention to detail during the construction process, and may provide some indication of potential future problem areas in the facility. Since the inclusion of items on the punch list are subjective in nature, depending on the critical nature of the observer, the number and types of items on the punch list for the commissioned facility required closer scrutiny. In reviewing the punch list line by line, many individual items appeared very minor in nature. This does not detract from the validity of the inspection product but indicates, in the case of the commissioned facility, circumstances and oversight which were provided on-site were instrumental in precluding major problems from occurring. This indicates the strong, functioning nature of the District's construction management together with the efforts of the CA in scrutinizing the project. The table below provides a synopsis of these items.

Table 13. Facility Punch list Items – Commissioned School

	Above Ceiling Inspections		Final Punchlist	
	Total Issues	Avg. Issues/Room	Total Issues	Avg. Issues/Room
Area A	31	0.9	177	5.2
Area B	35	1.3	131	4.7
Area C	23	1.9	43	3.6
Area D	32	0.8	220	5.2
Mezzanine A	15	1.9	98	12.3
Mezzanine C			35	11.7
Mechanical Area			99	24.8
TOTAL	136	1.3	803	9.6
GRAND TOTAL	939	5.5		

Post Construction Occupancy

As in the case of the baseline school, work orders were tracked and an analysis was done at both the six month period as well as the one year period after school completion. A log of all work orders for the commissioned school at the six month point indicated a total of 191 work orders in the system. This data was again tracked for one calendar year after occupancy with the total number of work orders reaching 302 for the facility. The total cost for the year came to approximately $38,200.00 with the year end breakout at about $11,500 for materials and $26,700 for about 1590 hours of labor (including both contractor and M&O Department personnel). Of this year end amount, a single work order to "Install New Security Alarm System" accounted for approximately $15,700.00 (labor plus materials) of the total cost.

For MEP-related issues, there were 116 total work order/warranty items with a cost of about $1000.00 for material and $5,900 in labor (300 man-hours). During the first six months of operation, MEP related work orders accounted for approximately 19% of the total cost and man-hours for the year. The table on the following page highlights work order areas and cost during those first six months of facility occupancy.

Table 14. MEP Related Work Orders – Commissioned School

	Number of Work Orders	*Cost of Work Orders*
Routine Maintenance	63	$ 3991
Preventive Maintenance	28	$ 2574
Warranty Issues	18	$ -
Vandalism	4	$ 147
Contractor Support for Projects Not Initiated by Maintenance	3	$ 284
New Work	-	$ -
TOTAL	**116**	**$ 6,996**

Continuing to track work order/warranty items for the remainder of the year indicated a downward trend in the overall number of work being reported, with the "strictly" MEP portion of the work indicating a slight upward trend, 63 for the first six months versus 71 for the remainder of the calendar year. These types of work orders were generally of the same nature as those reported in the baseline school. Leaking pipes, inoperable switches, hot/cold comfort calls, hot water calls, faucet problems, drains plugged, and some irrigation issues were typical of the items reported by staff at the facility. The table below indicates the numbers of work orders at six months and one year reported by the school district. As in the case of the baseline facility, numbers reported were divided by facility area to show values on a per 10,000 square foot basis. This was done in order to normalize units for later comparison.

Table 15. Work Order Trends/Totals – Commissioned School

	at 6 mos	per 10ksf	at 1 year	per 10ksf
Number of WO's	191	19.1	302	30.2
MEP Work Orders	116	11.6	149	14.9
MEP Warranty Items*	18	1.8	33	3.3

* Warranty items included in totals

Utility Consumption

As mentioned in the section of the report concerning the baseline school, there was particular emphasis on the potential impact of commissioning on facility utility costs. The expectation was that this area of the study would provide some evidence of the "quantitative" benefit from performing the commissioning process.

Utility bills for electric and natural gas consumption for the commissioned school were obtained from the school district's energy management staff. Energy use data was provided by the district in two formats. Summary data for electric and gas utilities provided monthly totals for kWh, demand, and ccf along with the costs associated with these amounts. Interval data (15 minute) for electrical energy consumption for each month of the study was also provided for input into simulations as well as for further spreadsheet analysis. Along with this information the team obtained information about the district's average energy use for all the elementary schools in the district. At the time of this analysis, there were a total of 51 elementary schools used in the determination of district-wide energy consumption which was based on the total number of schools, energy consumed at these schools, and conditioned floor area for these facilities.

Based on the data analyzed, the average monthly energy use for all elementary schools in the district is approximately 3.9 kBtu/sqft combining both electricity and natural gas. The most recent Commercial Building Energy Consumption Survey (CBECS) for 2003 provides data for selected facilities by region. For educational facilities in the south, the average energy is calculated to be approximately 6.0 kBtu/sqft. For comparison, the CBECS average is shown as a benchmark along with the district average for all elementary schools as computed from data provided to the study team.

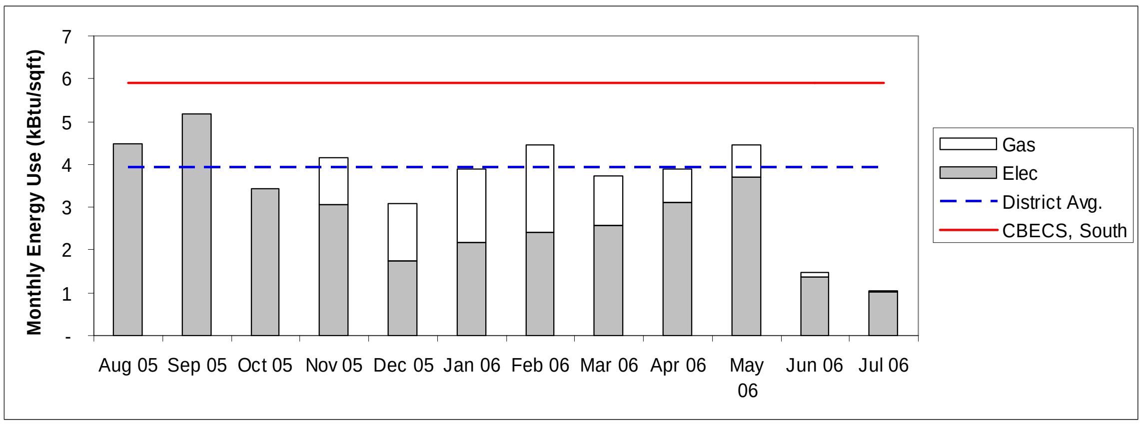


Figure 21. First Year Energy Consumption Statistics – Commissioned School

The figure above represents that information reported for electric and gas utility consumption for the commissioned school. The average monthly energy use for the commissioned school is estimated at 3.6 kBtu/sqft which breaks out into 2.9kBtu/sqft for electricity and 0.7 kBtu/sqft for natural gas. Overall monthly expenditures for energy averaged approximately $0.07/sqft for a total average cost of $6,735.00 per month.

Energy utilization for the building approaches the district average of 3.9 kBtu/sqft while cost/sf is slightly below the average for elementary school facilities in the district. Conspicuously missing from the graphical information presented above are cost data for gas consumption for the first three months of operation. It must be mentioned that although natural gas equipment was in operation during this period, the school district was not being charged for utility costs in this area. Gas utilities were still the responsibility of the contractor based on unresolved punch list items as reported by school district staff. In order to see a more complete picture of energy consumption in the facility, the missing data was generated by use of modeling based on area weather conditions and is presented in the following section for comparison with the above information.

As mentioned in other areas of this report, the trend noted during this study is that new school floor plan area is increasing. This trend was highlighted in the section on the baseline school, where the increase in area was roughly 6,600 square feet, while the commissioned facility was 19,000 square feet larger in floor area that the average elementary school in the district. This increase was directly linked to planning needs assessment performed by the district and the decision to increase school size based on demand in the local area. While building size can be readily associated to needs in the classroom, facility cost per unit area based on these increases may be positively or negatively impacted by this trend. Later discussion (see Findings) will present this aspect with respect to these individual schools.

Building Simulation

Sufficient detail and background concerning simulation has been provided during the discussion of the baseline facility that a complete reiteration to that level of detail would be redundant. Simple modeling and analysis techniques were applied to the commissioned facility in order to identify possible retrofit opportunities for future construction within the district. Some changes to the school district's design guide are being proposed and the ability to model a given application, schedule change, or equipment item provide necessary data in determining financial feasibility for any proposed design guide changes. Also, a model allowed for simulated, reliable data to be generated for the utility consumption analysis as mentioned in the previous section.

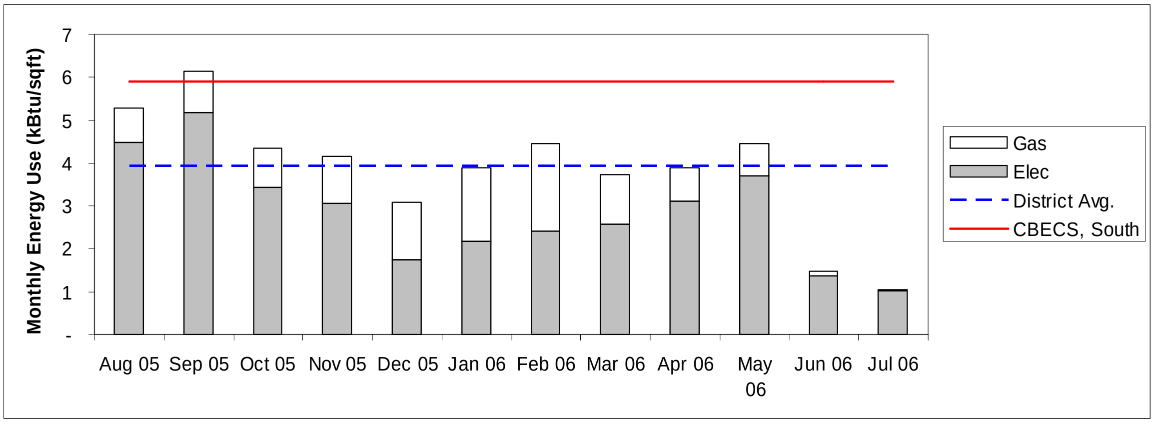


Figure 22. Energy Statistics w/ Gas Consumption (simulated) – Commissioned School

From the figure shown on the previous page, natural gas consumption data was generated by the model for the months Aug – Oct of 2005 and were subsequently appended to the energy analysis that was performed initially. These adjustments indicated overall energy consumption for the facility to be 3.8 kBtu/sqft with electric consumption at 2.9kBtu/sqft and gas now at approximately 1.0kBtu/sqft. This overall value approaches the calculated average of 3.9kBtu/sqft for 51 elementary schools in the district. This model increased the overall monthly average expenditure for energy to $6,958.00 for combined gas and electric utilities.

As in the case of the baseline facility, much of the information input into the facility model with respect to cooling and heating equipment was obtained from the energy management and control system (EMCS) for the commissioned facility. Equipment type, quantity and location were cross referenced with as-built drawings to ensure accuracy. This was also verified during site visits made to the facility. Sequence of operation, scheduling, on/off and setback was primarily from the EMCS computer screen shots. This information is invaluable in setting benchmark parameters for the facility's operation. The screen shot below gives an example of the equipment scheduling parameter as indicated by EMCS. The "effective time" varies by zone since occupancy schedules differ by location. The information is therefore AHU and zone specific.

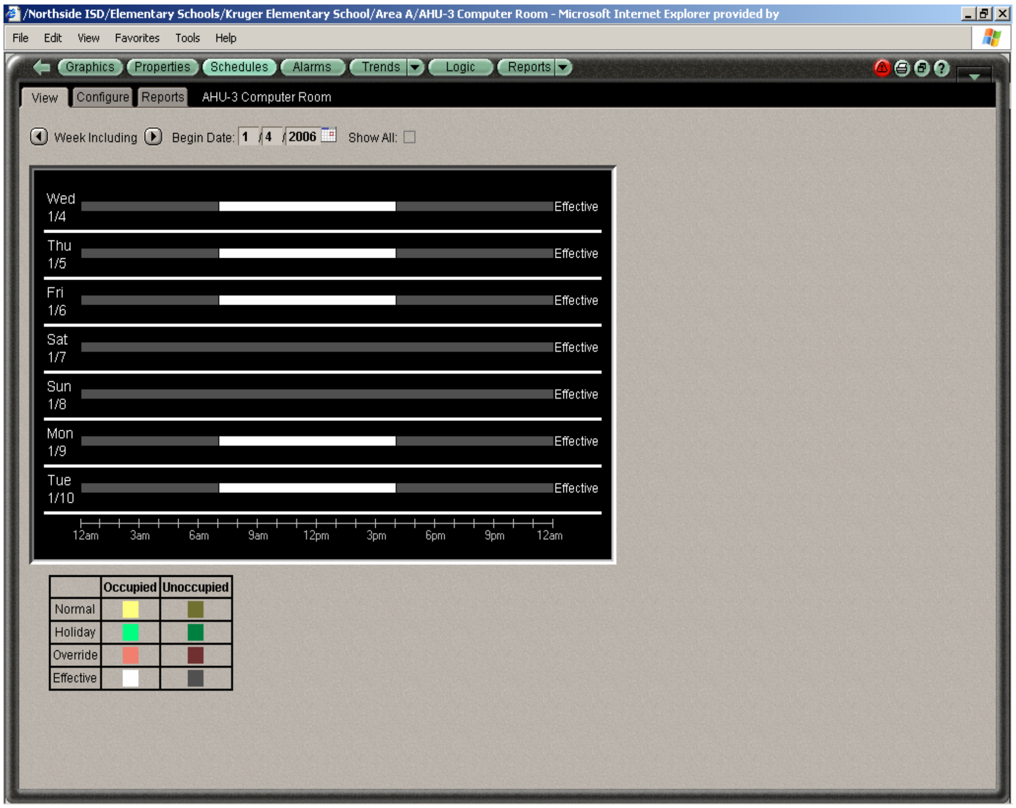


Figure 23. EMCS Screenshot for representative zone schedule – Commissioned School

Many if not all of the set points and system operating parameters are drawn directly from the district's design guide which acts as the master specification for the school district. Another source of input is from the district's energy management staff, which routinely performs trend analysis in each facility and across the district. Input parameters from the EMCS system require some form of correlation check with actual operation at the school as well as with information generated by the model. This is done in order to determine if what the system is commanding the components is actually taking place, and in the case of the model, if it will closely approximate equipment function and interaction.

In addition to scheduling of equipment, individual cooling/heating equipment items require set point values as indicated on the screenshot below, and changes to these values should be tracked if any simulation run is expected to yield satisfactory results. For the commissioned school this requirement included AHU's, terminal box components, outside/return air dampers, chiller operation, boiler operation, and numerous ancillary mechanical components (e.g. pumps, fans).

The figure below shows another sample screenshot which was used to provide operational characteristics of the building systems.

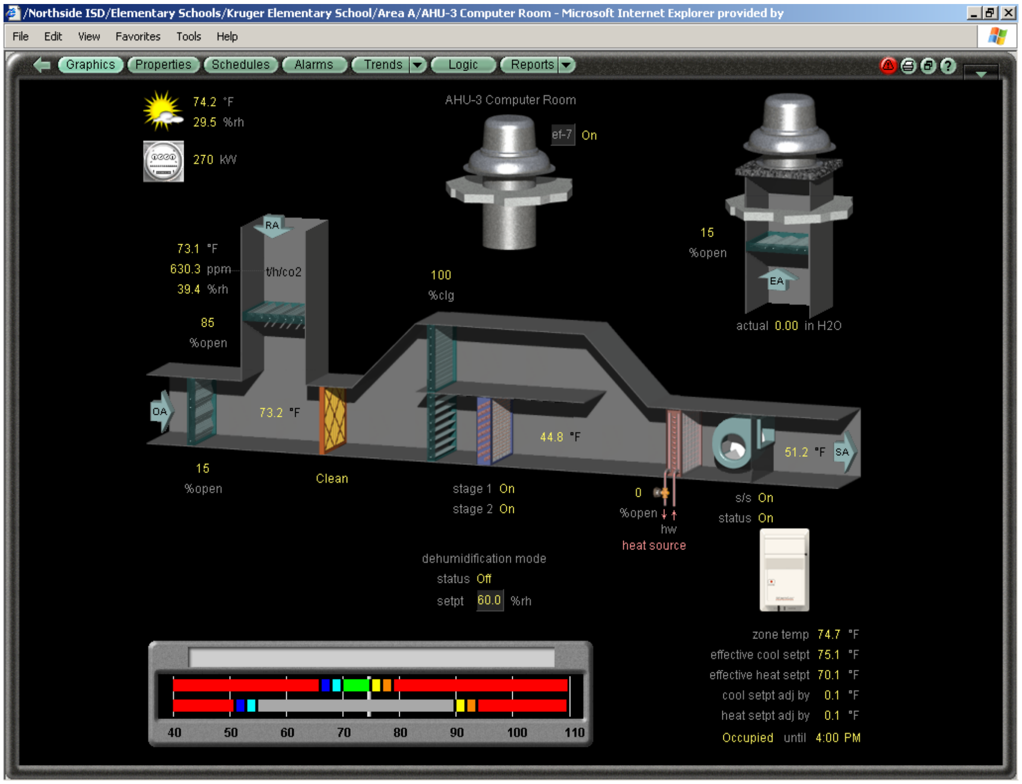
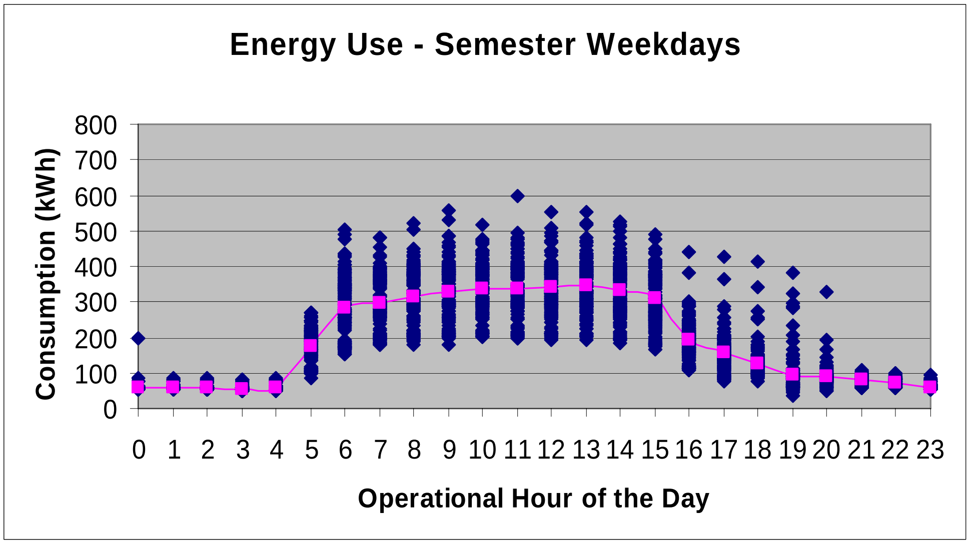


Figure 24. EMCS Screenshot for representative zone set points – Commissioned School

In comparing data sets, the measured data represents the information received from interval measurements provided by the utility company. Graphical representation is facilitated by exporting data into spreadsheets and displaying the recorded consumption values. The expectation is that the model will closely represent/approximate measured data, remembering that actual point values may vary, but general trends of operation are significant. Once operational trends are established and all equipment items/parameters have been accounted for, calibration of the model can be used to "fine tune" the simulation to provide any necessary offset. The figures on the following page show one method employed which computed averages of measured consumption on an hourly basis. A subsequent "model" was developed for that period and used to approximate the general trend of the data based on measured values as a function of the average for that hour. The given simulation should therefore follow this same operational trend with this same ratio for the simulated output.



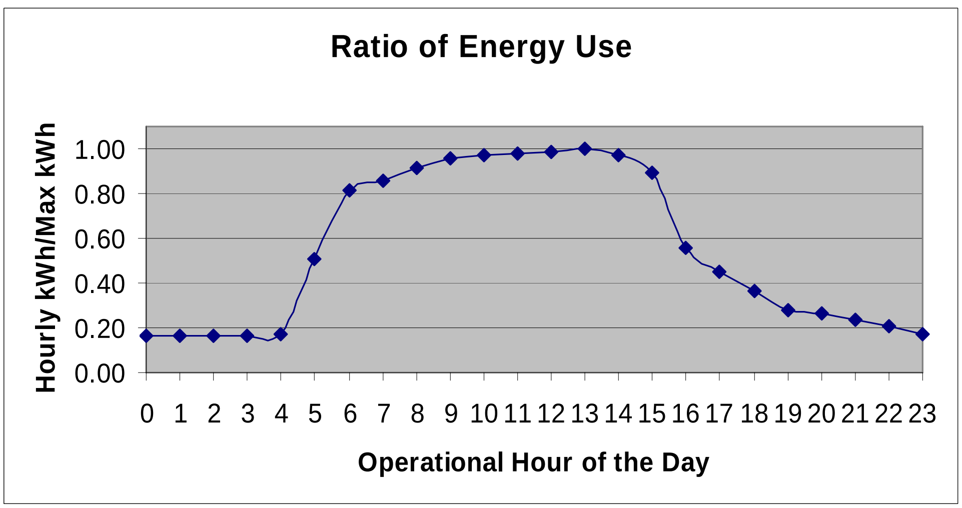


Figure 25. Operational trend with computed averages and ratios used in simulation

Measured data represented in the figure above is based on hourly data for the facility and on weather conditions at that time. Energy consumption values will of course vary based on seasonal conditions, as well as schedule and set points already mentioned in a previous paragraph.

As mentioned in the simulation section for the baseline school, the “bottom line” expectation is that the final simulation closely tracks measured input data. Exact duplication of values is not expected, while proximate values within certain tolerances should be the outcome. Also, the overall trend (slope) of the simulation should approximate that of the measured data as well.

As indicated on the plot, the calibration resolution (signature) is considered a measure of how well the simulated data tracks the measured data on a point by point basis. These differences ideally should cluster around the "zero" value indicating some relative measure of correlation between data points. For the majority of data points indicated the building simulated performance closely approximates actual performance and therefore will be considered useful in conducting further investigation of facility energy costs and equipment and construction options.

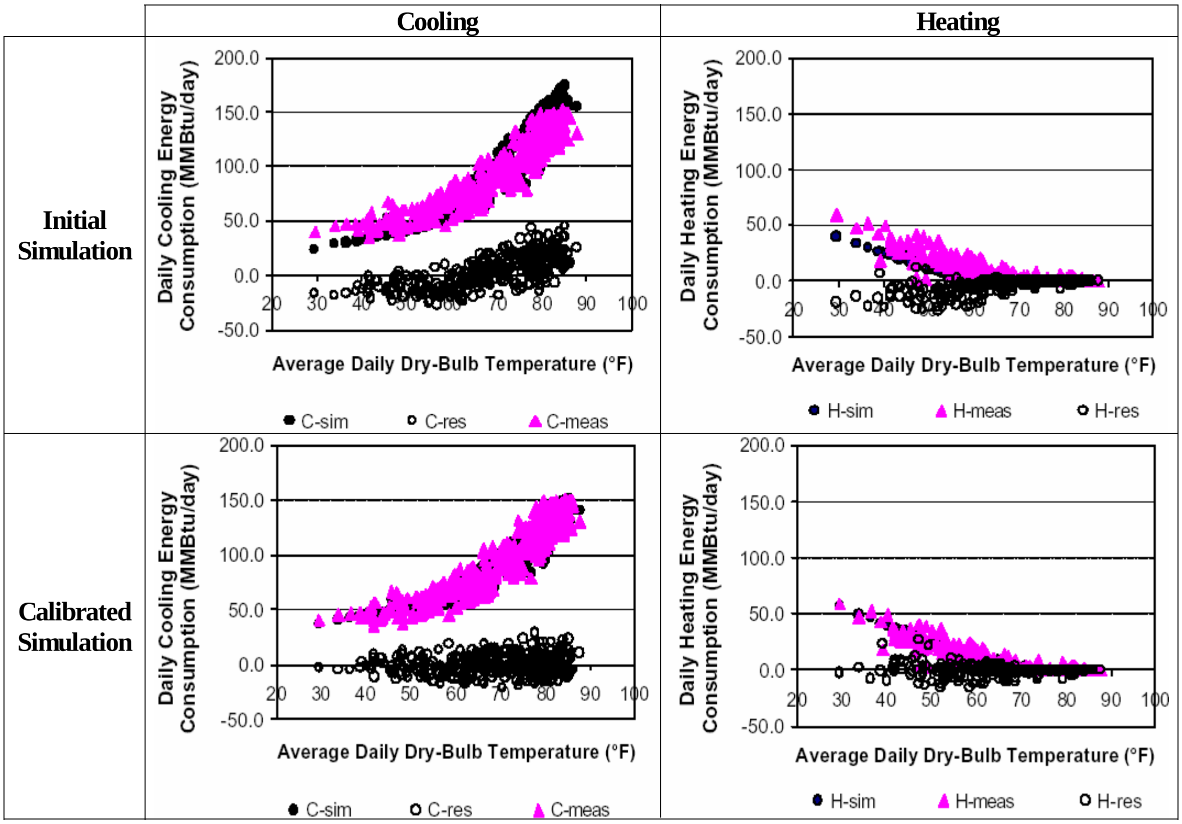


Figure 26. Example of pre-calibration and post-calibration simulations showing variation

Further discussion and energy comparisons between facilities will be addressed in the final section of this report.

Comparative Findings

In studies of this nature, after the Executive Summary, many readers find themselves navigating directly to the current section of interest. As many tables, graphs, and figures will show significant differences between the two schools in certain areas, there may be an inclination to attribute much if not all of the positive benefits to the commissioning process. Rather than proceed in such a manner, there are details and specifics of circumstances and conditions which were significant even in a study of only two facilities. This study attempted to highlight these circumstances whenever possible and make mention of them in the appropriate section of this report for the benefit of the reader.

Metrics

Before a direct comparison is made between qualitative and quantitative data gathered during the course of the study, the expectations of commissioning and benefits sought with respect to established metrics will be presented.

Schedule

By identifying and addressing issues during design rather than construction, avoidance of trade stacking during construction, and by avoiding change orders and punch list items, the construction schedule should be more predictable and fluid. This may also translate into a shorter construction schedule as well. This should result in reduced construction costs to the contractor, and these reduced costs will be passed on to the owner.

Change Orders

By identifying issues earlier in the planning and design phase, major changes can be addressed at a lower cost, rather than as a significant change during later stages of design or as a construction change order. Many items identified through the commissioning process would be discovered at a later point, so that the cost of addressing the items is not avoided. However, issues addressed in the design stage are less expensive than those addressed in the construction stage. Also, the owner typically pays a premium for work done on a change order rather than as part of the original contract, due to the need to react quickly. Expectations were that through increased oversight of the CxA, change orders and the resultant impacts on schedule could be avoided.

Punch List

By avoiding unexpected issues, and dealing with them in an orderly fashion, as they are discovered, there will be fewer issues remaining at the end of the project. Typically, the owner does not have to pay extra for completing punch list items. However, punch list items create unnecessary hardship for both the owner and the contractor, and some items may be left unaddressed due to everyone’s desire to have the project completed. It may also be more expensive to the contractor to address the items at the end of the project rather than during the construction depending on the nature and scope of the finding. By reducing the number of punch list items, the impact on the owner’s staff and contractor’s costs at the site should be significantly reduced. In reducing the number of punch list items, facility turnover and occupancy flow more smoothly since contractor personnel do not remain on site during staff move in.

Problem ID – Facility Maintenance

While the building is being turned over and during its early stages of occupancy, any newly constructed building will typically require significant time for building operations and maintenance staff to fix minor items that were not implemented correctly, tuning environmental systems/controls, and general "debugging" of problems encountered by the occupants. The difference between these and typical work orders are that they generally need to be addressed in "short order" prior to student's arrival. Much of this extra time can be avoided in a commissioned building. It is expected that the CxA will identify certain issues and notify the proper individuals for problem resolution prior to substantial completion. This added benefit will not impact facility modifications due to occupant needs identified after building staff moves into the new school.

Callbacks – Warranty Issues

After occupancy, it is common for the contractors or subcontractors to revisit the site to remedy deficiencies that are discovered during the facility's initial operational period. Depending on the nature and severity of the discovery, some items may be tagged as warranty service issues. This may then involve equipment vendors also revisiting the site. Under certain circumstances, equipment/systems may be shut down for repair and/or replacement. This places undue hardship on building occupants, while district staff tracks status through completion on each issue. In a commissioned building, these callbacks can be reduced, since many deficiencies will either be avoided or identified in a systematic way prior to occupancy. Typically, the owner does not have to pay extra for these call backs, although it takes staff man hours to deal with these problems. It is also less expensive for the contractor to address the items during construction rather than after the project completion.

More Suitable Building – Meeting Owner's Intent

Once the building is complete and occupied, it is very likely to still have deficiencies that were not identified or were not addressed during design, construction, or turnover. In some cases these discrepancies are the result of an incomplete understanding of the owners (read occupants/staff) design intent. This can also be read as "what building users want in their facility". A wish list can also come from the building maintainer's side of the house as well. Defining this area can be difficult since it may impact areas in the districts design guide not to mention potential budget impacts. It is also a difficult task of defining "actual needs" versus "nice to have" items. Increased scrutiny directed at lack of functionality, occupant discomfort or complaints, inordinate maintenance requirements, and potential increased operating costs can be the task of the CxA. Commissioning ensures that the intent of the owner and the occupants is met through documenting and prioritizing significant owner's requirements, and matching building design and construction to meet the owner's list of requirements. This occurs if the CxA is engaged at the earliest possible stage in the design process. The expected benefit of commissioning should indicate increased occupant/staff satisfaction with their facility. Many of these "benefits" are not quantifiable and come from interviews, private discussion, and surveys.

Reduced Energy Use
Through the commissioning design review process, all appropriate energy efficiency measures may be evaluated and implemented where deemed cost effective and otherwise appropriate to the building. The energy implications of other design decisions can be reviewed, discussed, and changes may be made as needed. Errors in design and construction, which often result in sub-optimal energy performance of building systems, should be avoided in any commissioned building. Functional testing of integrated systems also helps to optimize building energy performance. Building systems that can be easily operated and maintained (and for which training and documentation have been provided) have improved performance: commissioning ensures that the building is maintainable and that training and documentation are provided. Investigation into any impacts of the commissioning process on these types of factors will prove beneficial to any future design/construction project. Through analysis of the building's energy consumption and comparison between facilities, identification and characterization of optimal performance is expected. The role that commissioning will play in reaching this level of performance is extremely important in times of increasing energy prices.

Operation and Maintenance
Since a fully commissioned building should have fewer equipment/systemic defects, it should cost less to operate and to maintain. Fewer problem calls during initial occupancy should be received by the maintenance staff. Functional and operational testing as part of the commissioning process should result in fewer "surprises" as a result of incorrect or incomplete component installation. The training and documentation that commissioning provides improves the effectiveness of the O&M staff, and reduces the O&M costs through reduced man hour expenses. The expected benefit would be reductions in problem calls and reductions in unplanned maintenance activities and fewer overall work orders in the system. The impact of course is less maintenance backlog, a better operating facility, and again increased occupant/staff satisfaction with the school.

Equipment Service Life
This is seen as an essential by-product of the commissioning process. Design reviews, installation verification, and functional tests should preclude any equipment or control deficiencies that might lead to inappropriate equipment operation and premature failure. The value of lowering the failure rate is reduced equipment downtime, avoiding undue replacement cost, improved comfort and customer satisfaction, reduced O&M expenses, and potential reduction in energy costs. Commissioning is viewed as a method to help the owner head off these unnecessary problems by providing oversight in critical areas of equipment installation, testing, and initial startup.

Direct Comparison

At the outset of this process, many observers and industry professionals were keenly interested in the results and findings of this study. According to many individuals, although numerous papers had been presented on the merits of commissioning, this was a first attempt at purposefully selecting two facilities in a side by side comparison where building function, design, and operation were similar. It was fortunate that the architect was the same for both projects. This fact tended to minimize variation in design style as well as layout. The fact that MEP designers for both buildings were required to use the same basic school district design guide (w/o significant alteration) also served to minimize variation in this area of the study. The figure below reflects a side-by-side view of both schools in the study. They are *not to scale* since the baseline school (Blattman) area was approximately 86,000sqft while the commissioned school (Krueger) was approximately 100,800sqft. Factors responsible for this variation in size are presented in previous sections of this report.

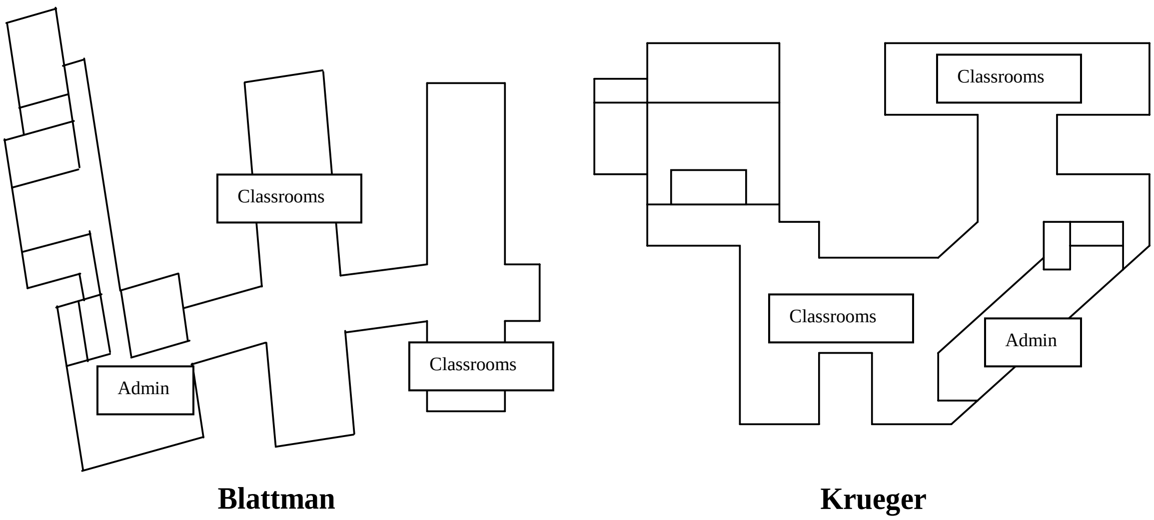


Figure 27. Building footprints and layout for both schools in this study

In the body of this report under the sections for the individual schools, the pattern was to discuss design/construction findings, transition into energy analysis, and finally to conclude with the topic of building simulation. That same format will also provide the pattern for this final section of the report with the exception that discussions on building simulation, qualitative survey results from facility occupants and key district staff, and lessons learned will be mentioned within concluding segments to this section.

Design and Construction

In each area that was observed under this heading, a metric was established which was assumed to provide key information either about a specific portion of the design and/or construction process, or the state (read effectiveness) of the overall project process from beginning to end. The table on the following page indicates the cumulative results of those metrics as reported for each school.

Table 16. Cumulative results of observed metrics – Baseline School/Commissioned School

Metric	Description	Blattman ES		Krueger ES	
RFIs	Number of MEP-Related RFIs (per 10,000 sqft)	2.6		2.4	
	Average Number of Days in Review	9		13	
Change Orders	Number of MEP-Related Change Orders (per 10,000 sqft)	4.4		1.4	
	Cost of MEP-Related Change Orders (% of Construction Cost)	0.9%		0.4%	
Punchlist	Average Number of MEP-Related Punchlist Issues per Room	2.7		1.3	
Schedule	Difference between Expected and Actual Duration of Design Phase	-5.5%		11.4%	
	Difference between Planned and Actual Duration of Construction Phase	26.7%		11.9%	
Cost	Difference between Expected and Actual Design Cost	-4.2%		7.1%	
	Difference between Expected and Bid Construction Cost	-4.7%		6.1%	
	Difference between Bid and Actual Cost	1.2%		3.4%	
Post-Occ Eval.	Number of Significant MEP-Related Issues Identified in First Year	5	*	5	*
Work Orders	Number of MEP-Related Work Orders in First Year (per 10,000 sqft)	14.5	*	6.3	*
	Cost of MEP-Related Work Orders in First Year (per 10,000 sqft)	$1,079.00	*	$396.00	*
Energy Use	Electricity (annual kBtu/sqft)	42.5		34.2	
	Natural Gas (annual kBtu/sqft)	14.5		9.0	
		* = first six months			

The table is shown with side by side values to allow for easy comparison of observed metrics. Without further explanation in several areas, some reported results may tend to misrepresent the particular area observed. The following explanations are provided here as a supplement to the above information and are offered in more detail in previous sections of the report:

1. The cost of MEP related change orders (% of Construction Cost) are reported for individual purchase requests submitted to the district through the A/E from the contractor. These requests were generally combined based on number/type and paid under the Contingency Change Order (CCO) system administered by the district's Facilities Construction Department.
2. The cost of Change Orders (CO's #1, #4) for the commissioned school which involve school expansion and acceleration of construction schedule *are not included* in the cost of MEP related change orders, although each of these majors CO's had an MEP component associated with them.
3. With respect to scheduling, percent variation in design and construction phases of the project for the commissioned school are reported *with changes* to building expansion and accelerated schedule (CO's #1, #4) as these would be extremely difficult if not impossible to break out from the overall timeline of the project.
4. Construction cost differences *include changes* (CO's #1, #4) in the above information provided for the commissioned school. These values can be factored out to indicate variation without these changes. Doing so yields a difference of only 0.4% between the bid cost and the actual construction cost.
5. Although not provided in detail in the report, the case can be made that due to the addition of classrooms through the change order process, design cost would increase as well. No specific delineation of events allowed for this breakout and therefore, the difference between expected/actual design costs remains at 7.1% as shown above.
6. Reported values for the occupancy phase for both schools are shown for the period to include the first six months of operation. This was done to highlight the significance of this timeframe from the M&O perspective. Information obtained during continued monitoring throughout the first calendar year is presented in previous sections of this report.

7. The annual natural gas consumption is reported as the actual amount based on the districts utility records. Since the contractor retained responsibility for natural gas billing for the first three months of beneficial occupancy, a more realistic value, based on modeling, would be approximately 11.7kBtu/sqft annually for the commissioned facility.

Some of the most significant items of note in the table will be pointed out. They are selected since professionals familiar with the design and construction industry will verify that any reduction in these areas translate into time and/or money savings for the project. Of particular note are the reductions in number and cost of MEP related changes orders, which were reduced in both cost ($95,000 vs. $49,000) and in number (38 vs. 15). One of these change orders was actually a decision to upgrade equipment based on commissioning input. This was the accepted proposal to change from standard motors in fan coil boxes to electronically commutated motors. The next obvious area of “improvement” was during the post occupancy period, and was highlighted by the significant reduction in the number and cost of MEP related work orders. Work orders numbers were reduced by almost 50% while cost of these work orders was decreased by over 60%. The final area of note is in energy consumption values where the larger commissioned school experienced an average annual savings in excess of $16,000.00 over the baseline facility. The topic of energy savings and related issues will be addressed further in the following section.

Energy Consumption

Since the commissioning process in this study focused on the mechanical, electrical, and plumbing areas of design and construction it was expected that this emphasis would have some measurable impact on the facility energy utilization. The figure below indicates total energy consumption for each facility over the first ten months of operation. This time frame was selected based on the approximate length of the school year. Since operation, schedule, occupancy, and equipment utilization becomes more “variable” during the summer break, the ten month period was selected to ensure some degree of consistency in reported results.

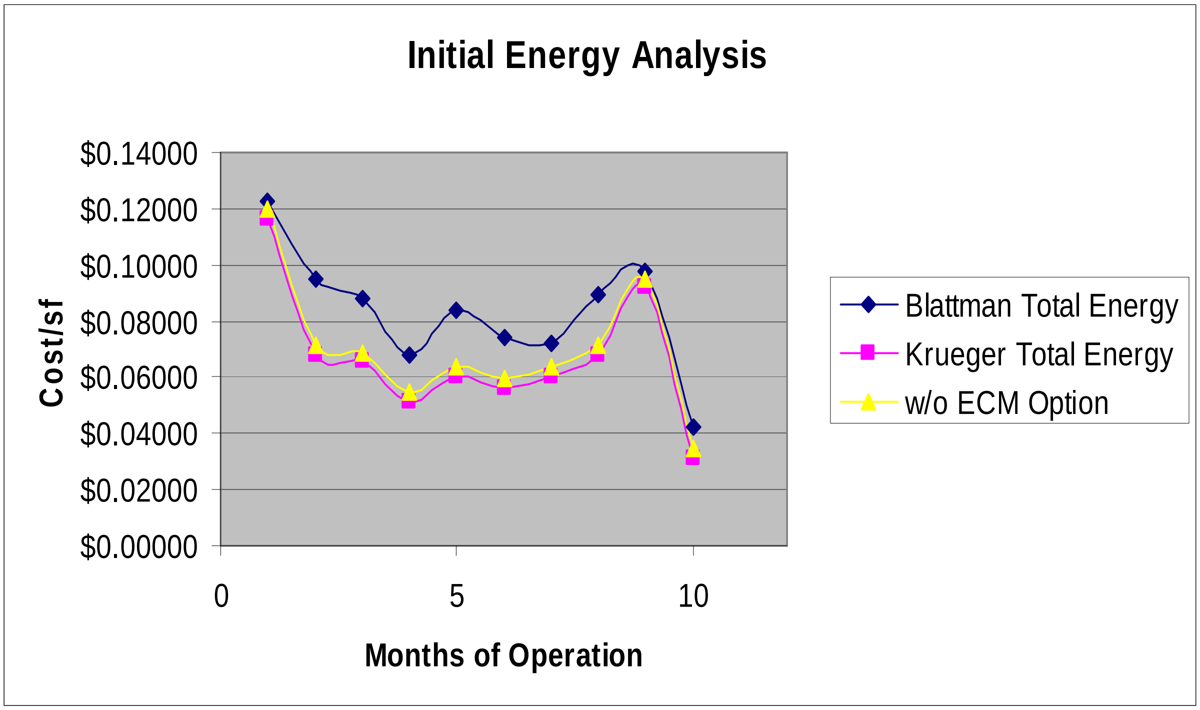


Figure 28. Energy cost comparison between baseline and commissioned buildings

This figure above provides easy comparison of the observed energy metric for the two schools in the study. Again, without further explanation in several areas, the reported results may tend to misrepresent the particular area observed. The following explanations are provided here as a supplement to the above information and are explained in more detail in previous sections of the report:

1. Initial energy costs during first billing cycle reflect equipment startup and testing as the district attempted to certify operation of major components and systems. This operational "wring out" takes place prior to staff occupancy and is crucial to work order and warranty service issues.
2. The first truly operational period is considered as the first billing cycle after the school year begins. This is indicated by the second data point in the series for each facility.
3. Values indicated were normalized for month days as well as taking into consideration major variation in weather/temperature between operational periods.
4. The final month indicates a portion of time where each facility is beginning to ramp down for summer break. This trend is obvious by decreased energy costs attributed to decreased equipment utilization.
5. Since the goal was to report "realistic" total energy costs, the series for commissioned school includes values obtained through modeling efforts with respect to natural gas consumption for Aug – Oct 2005.
6. Months of operation for each school is as follows: Blattman ES Aug 03 – May 04 and Krueger ES Aug 05 – May 06

The only design change that can be "directly" attributed to the commissioning process is the addition of electronically commutated motors (ECM) to fan powered boxes throughout the school. An economic analysis was performed which indicated initial costs (vendor estimate) for the change at $16,560.00 for 72 fan powered boxes throughout the school. The actual cost as paid by the district was $20,051.00 as indicated in the change order. Based on operation of the equipment and an estimated annual energy savings of $2,590.00, simple payback for this modification was estimated at approximately 7.7 years. Calculations were based on average monthly expected utility rates ($0.07/kWh), and current operating trends/schedules for equipment in the district. The figure on the previous page also indicates series data with this "known" cost savings removed for comparison.

It becomes obvious that there still exist some factor(s) inherent in the commissioned facility which result in the remaining energy cost difference. The overall energy cost savings (w/ ECM) in the facility is approximately $16,300.00 annually. Since the cost for commissioning of this facility was a known quantity as specified through contractual payments, the simple payback is calculated to be approximately 5.3 years. Since school districts retain property far in excess of this time, it is expected that a high percentage of this savings will continue to be realized by the district. A major caveat to this approach assumes that all savings are attributable to the commissioning process. This may not of course be the case, since there are many potential opportunities for system improvement through design, construction, and component installation. This was recognized by the study team and removal of the ECM benefit amount from the analysis yields an approximate savings of $13,700.00 annually.

Many of the school district's M&O staff members were veterans of numerous school construction projects during their tenure with the district. Construction management and engineering personnel also had many years of experience at new school construction in the district. Throughout interviews and discussion with these individuals, it was often mentioned that "there was a feeling" that the contractor and subcontractors were aware of the CA presence on this project and due to that fact the workmanship and attention to detail improved. This particular comment leads directly to qualitative improvements which were noted by numerous district staff members and the CA on the project site.

Building Improvements – Simulation Analysis

As part of the completed study, the building simulation for the baseline school was used as a tool to investigate and quantify possible "improvements and modifications" to the existing facility and display the resultant impact on building energy consumption. These changes to the modeled building were developed in brainstorming sessions with school district engineering and maintenance staff at the directors' level. Some changes which were input into the model could be considered as potential recommendations if commissioning had been accomplished on the building. Variations to facility design with resultant energy savings can also provide added incentive to make necessary changes to the district's design guide. Calibrated models, as mentioned in previous sections of this report, are capable of mimicking equipment and system interactions to the extent that a single change in schedule, set point, building structure, equipment type/operation, and numerous other input parameters are translated into energy consumption figures for the given change.

For the purpose of this exercise, changes to selected parameters were input singly to determine individual impact on facility energy use. This change was then "undone" and the subsequent selected parameter was changed. Although this was more time consuming from a programming and computer runtime standpoint, it was less complicated than trying to "unravel" which input had significant impact on the facility. It is possible that in combination some changes to model input would have yielded much different results.

It is obvious from each data set which follows that optimization of individual parameters was not considered the goal of this process. The overall objective was to incorporate these changes into the model to provide some perspective as to the benefits of the modeling process and give designers and energy managers a starting point to investigate various options for energy reduction measures in the facility.

The figure below indicates that a change in building orientation would give rise to a small reduction in energy consumption for the building. This change in orientation consisted of rotating the entire building footprint on the building site. This was easily accomplished in the computer simulation. The impact of this change would affect such parameters as shading, percent direct/indirect sunlight, and wind effects, all of which are related to energy consumption in the building. It is possible that some angular rotation less than or more than that shown in the figure would yield increased percent energy savings different than that indicated. Since each simulation run took on average an hour to process, with no other computer operations possible during this time, it was not possible to optimize this (or other) selected changes due to obvious time constraints.

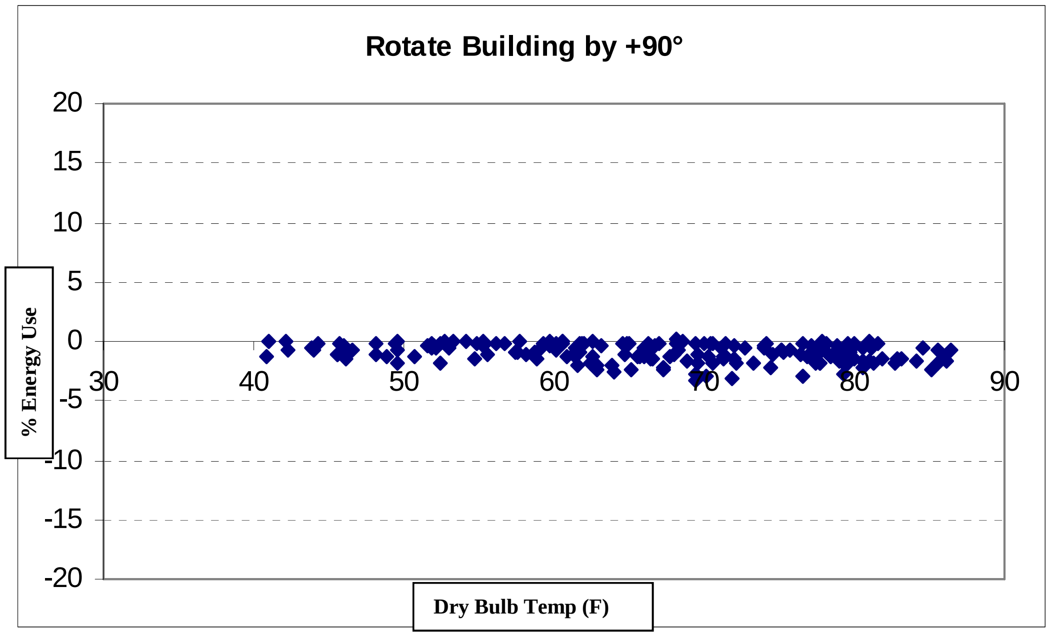


Figure 29. Energy reduction accomplished by a change in building orientation

For the case of building orientation, it should be noted that site conditions may not be amenable to this type of change, but it is shown regardless, since it is possible that a different orientation that is acceptable may yield some worthwhile savings to the building owner when considering future construction projects.

As expected, the use of low-e glass is dependent on ambient temperature and solar positioning. This case would also be linked to and could be optimized by changes in building orientation. Also, the change in glazing type will have a definite cost component which can be evaluated through the cost benefit analysis, unlike the above change to building orientation which, depending on site conditions, may not affect actual construction cost of the facility.

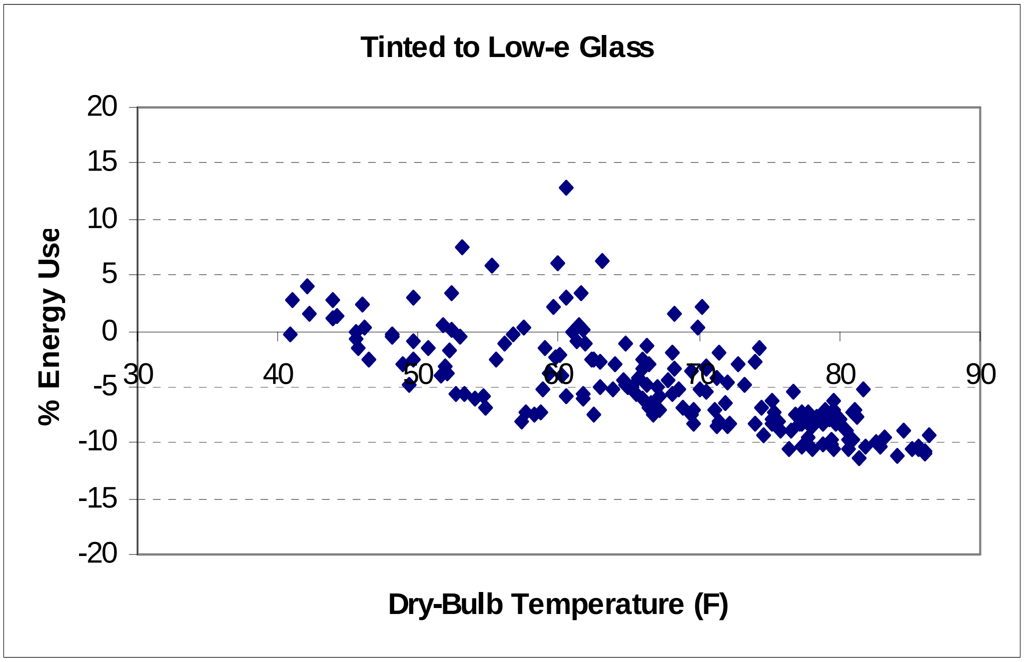
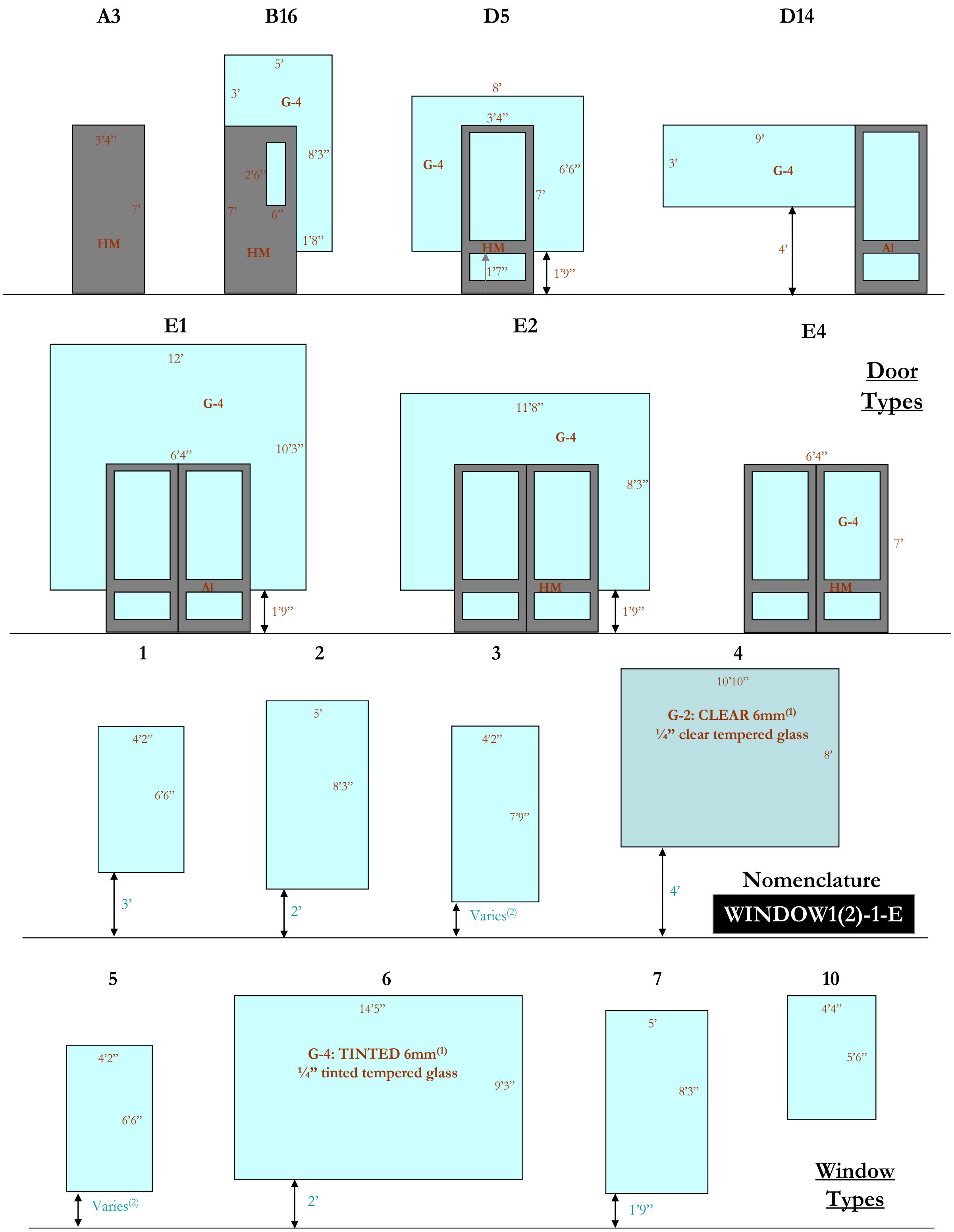


Figure 30. Energy changes accomplished by a change facility glazing type

The remaining selected cases shown in the proceeding figures all fall into this same basic category, where costing of the change could be evaluated against potential energy savings offsets which will help decision makers arrive at an appropriate solution.

An example of the following changes that might be considered is shown through actual comparison of facility components for the baseline school. Various glazing sizes and types were actually implemented as part of the building model when developing the simulation and in calculating results for this and other sections of the report. Those architectural types shown are only a representative sampling of the glazing combinations in use throughout the District. Mixing and/or changing actual specified components could yield substantial energy savings in combination with building orientation and other selected parameter changes. The figure on the following page shows a handful of potential changes that can be adjusted in the facility model. In making the decision to change any glass component, the expected energy cost, cost of reduced materials quantities, and affect on day lighting should all be considered.



(1) MATERIAL:WindowGlass, (2) 1' 9" except on wall 10-X-S1 (3'), (3) 1' 9" except on walls 8-X-N1 and 10-X-N1 (3')

Figure 31. Potential glazing component options used in facility energy modeling

Based on the options available, the model was changed to reflect an overall decrease (approximately 50%) in glazing area for the entire building surface area respectively. The figure below indicates there is a component of temperature dependence for any change in glazing quantity as expected. This parameter was not included with a change in building orientation, although it could be assumed that shading, in combination with direct/indirect sunshine would affect percent energy use as well.

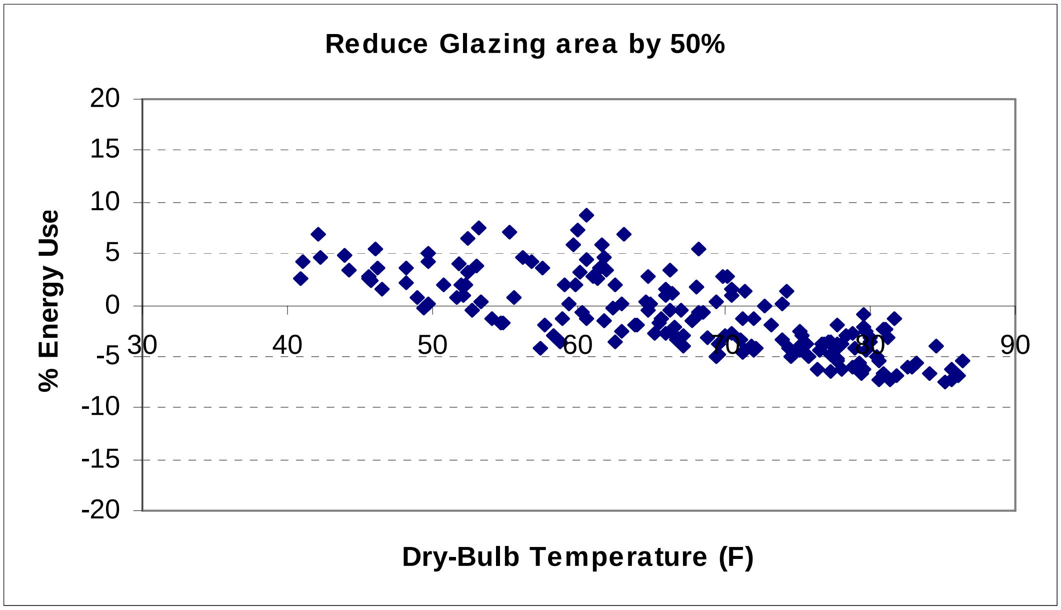


Figure 32. Energy changes accomplished by a change facility glazing amount

The remaining two cases are presented with obvious results to indicate the efficacy of the model under expected circumstances. Although it is doubtful that a facility wide fixture change would be feasible, selected changes in areas where day lighting is abundant would produce some noticeable result. Also, these changes would allow energy management to present a case for light fixture reduction based on this data as well as published recognized standards (e.g. Energy Smart Schools, Energy Design Guide for High Performance Schools).

The particular case represented in the figure on the following page took only classroom and common area lighting into account. Specific attention was given to reduce lighting in areas which had ample day lighting. Specialized lighting, exterior lights, security lights, gymnasium lights, and utility/mechanical/equipment room lighting was left unchanged. The reduction in the number of bulbs per fixture is based on the use of high output reflectors, and the direct substitution of these fixtures. The computer model was changed to reflect the reduced quantity of energy consumed based on the total number of lamps. The model accounted for reduced heat loads due to reduced bulb/ballast heat output throughout the facility. The overall reduction of only 2.5% is a mix of reduce energy consumption resulting from reduced number of bulbs and any environmental benefits from reduced heat load. Based on facility plans and electrical lighting diagrams, this reduction was calculated at approximately 15% of the total lamps in the building.

It should be mentioned here that any changes in light fixture type or output lumens must be verified through use of appropriate lighting calculations.

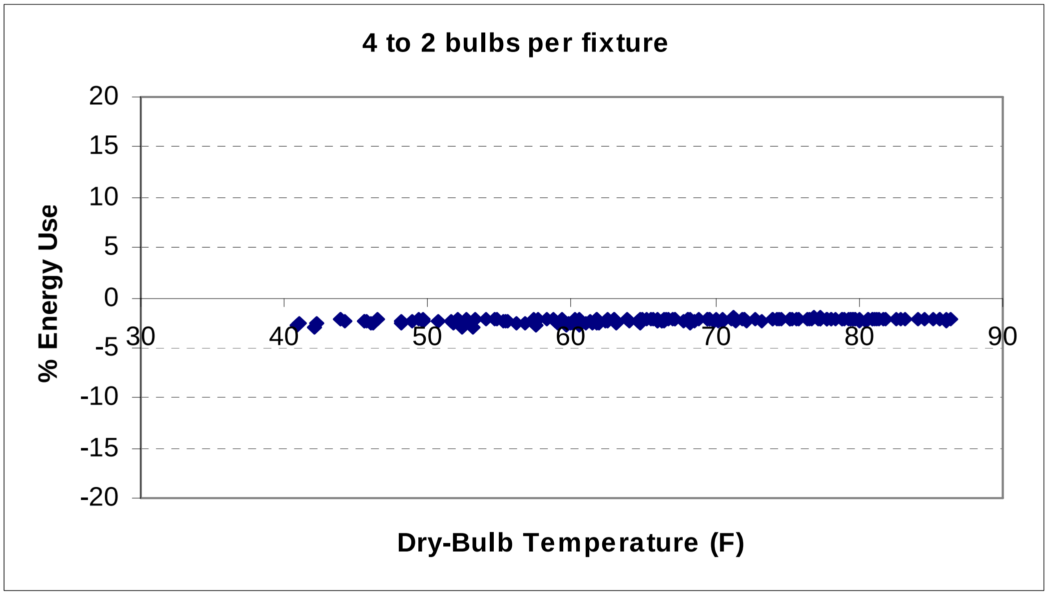


Figure 33. Energy reduction accomplished by change in facility lighting

As expected, any change in the comfort controls/equipment set points will have a noticeable change in energy consumption for the facility. The figure below indicates a tighter correlation at higher temperatures. At lower ambient temperatures, internal heat load in many areas of the school may still require some cooling components to be active (e.g. cafeteria, kitchen, etc).

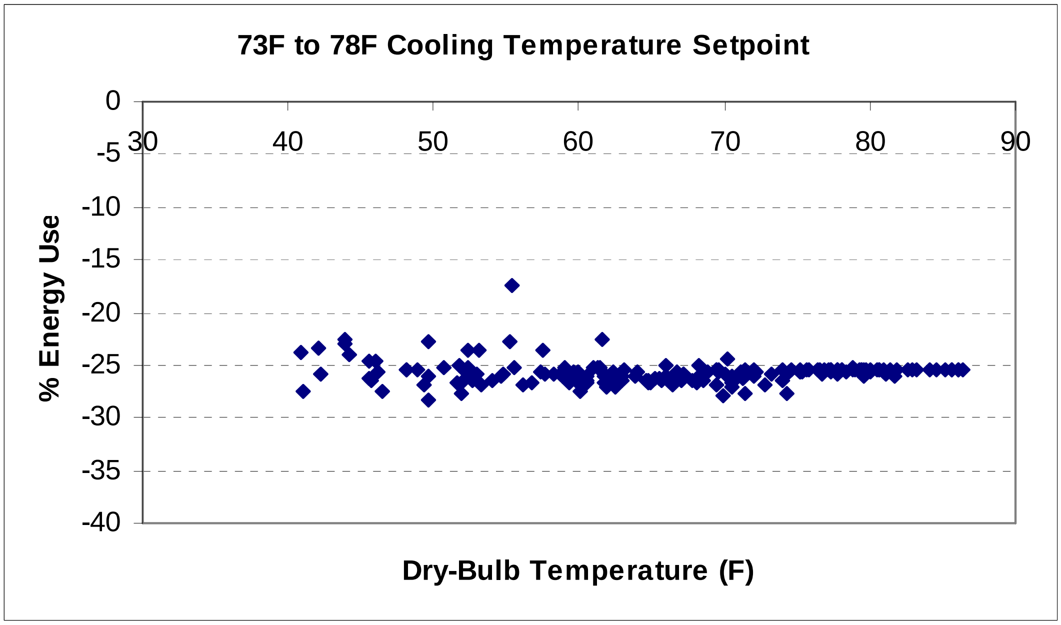


Figure 34. Energy reduction accomplished by change in facility cooling set point

The figure on the previous page represents what might be considered an aggressive change in cooling set point. This temperature was chosen as it represents that value typically mandated in many state and federal office buildings. It is also recommended by many local utilities as a residential cooling set point. With improved building practices and better materials, higher efficiency equipment, and the most recent discussion about trade-offs between outside air quantities versus improved filtration in schools it was considered as a viable option in this case. For this area of the country, and considering reduced outside air volumes, lowering indoor relative humidity would drive this set point selection. For further information, a simple interpolation between set points indicated (73^0F to 78^0F) would provide an approximate linear correlation between temperature and percent energy savings.

Another area for future investigation which might be of interest would be the alteration of wall structures with varying insulation types and resistance values. This type of change coincident with changes in glazing type and/or quantity could yield energy savings that could be expected to coincide with changes in ambient temperature. Several of these changes in combination could reduce facility construction costs and provide long term energy savings as well.

A proposed case for future investigation would be the development of a “generic” facility model for schools. This model would be multi-zoned, and equipment specific for the building in question. It would be written to sufficient detail to allow for optimization of individual parameters such as was accomplished above. Weather data would of course be location specific. This template model could provide designers and decision makers with much needed energy information in order to evaluate energy conservation measures prior to construction.

Conclusion

The course of this study spanned the time frame from May 2003 thru August 2006. During that period, the building commissioning study has adapted to changing circumstances with the goal of documenting commissioning benefits as they relate to the facilities mentioned in this report. The viability of new school commissioning was based on the comparison of selected metrics outlined in this study and explained in detail in previous sections of this report. Again with only two schools being observed, this study cannot be considered statistically significant, but must be taken on the merits accorded the information provided. Researchers and participants in the study have benefited greatly during this learning experience and the results presented are of both a quantitative as well as a qualitative nature. This final section provides a recap of results mentioned in previous portions of this document as well as some valuable study observations recorded and mentioned for future commissioning efforts.

For the commissioned facility, significant reductions in the number/cost of MEP related change orders were noted. Numbers of change orders dropped by a factor of three, while cost of these change orders was reduced almost 45 percent. Post occupancy MEP work accomplished by maintenance and operations staff in the commissioned school showed significant improvement with overall numbers of work orders decreasing by 50% in the first six months of occupancy and material and labor costs for these work orders decreasing by almost 60%.

Energy analysis performed on both facilities indicated that the commissioned facility cost the school district an average of $0.016/sf less per month to operate than the baseline building; a documented savings in excess of $16,000.00 annually. Based solely on this single, quantifiable result, the derived payback for this facility was 5.2 years. Quantifying and incorporating other noted improvements in post construction maintenance/operations and occupancy issues would reduce this payback period to below that already noted above. With these and other points mentioned in the report, the benefits of commissioning became apparent to district staff and researchers alike.

Lessons Learned and Recommendations– A Qualitative Approach to the Commissioning Process

During the course of the study, many observations were noted with relation to the commissioning process. Some of these were attributed to the "act of commissioning", while other observations were considered more perception oriented, based on the acceptance and understanding of the process by all parties involved. In presenting these comments, it is understood that although some of the items may be relevant to any given commissioning project, some may be specific to the study conducted. All noted items are provided as part of the study process and also in anticipation of informing future participants in the commissioning process of potential areas of concern.

The following section is derived from many different sources of information and observation. Some examples are facility surveys, personal interviews and conversation with staff, comments made by workers, and site visits by the study team. The type of presentation selected will be bullet statements followed by a brief description of each item. This method was chosen for ease of review and quick scanning of the list. Many of the "observations" are subjective on the part of the research team or the person making the comment. In some, but not all cases, specific details of the comment will be introduced. This is not meant to target any specific individual, group, or organization and all lessons learned are intended to be positive. One objective that should be understood by all readers is that "process improvement" is the overall goal. Again, the objective is to provide potential commissioning patrons the opportunity to highlight areas of concern should they choose to undertake facility commissioning in their particular organization. The general nature of the lessons learned is qualitative in nature and is relevant to all participants of the process.

- *Conducting a study "changes things"* –This comment refers to the fact that when people are being observed, they tend to do things differently. People either became more meticulous about certain details, or defensive in some cases. This can also be said of the commissioning process in general, where different people throughout the process viewed it with either anticipation or hesitation.
- *Early misconceptions and misunderstandings* – Although every effort was made to explain the commissioning process "up front" to all involve parties, many of the district staff and design/construction group were unclear as to the CA's purpose and their integration into the project.

- *Expectations of outcome were elevated* – Many individuals had overly aggressive ideas of what commissioning would accomplish. Trades personnel perceived that somehow commissioning would bring about a school without any problems/flaws.
- *Follow-up PR was lacking* – Even with several briefings at design and construction start, many people lacked a clear understanding of what the commissioning agent was doing, where they fell in the chain of command, and what was his authority on the jobsite.
- *Too many participants at the outset of the process* – Comments from key district and design/construction personnel alluded to the fact that too many people were involved in the study at the outset. Confusion increased during the initial stages as many varying perceptions developed as to "what commissioning does". This was attributed to the fact that since it was a first time effort for the district as well as the study team, it was thought better to include more individuals at the beginning rather that to have multiple briefing sessions as the project progressed.
- *Structure of responsibilities was unclear* – This was considered a problem due mainly to the way in which the study team was combined. The CA was in this case contracted directly by the lead scientist for the study team. In actuality, the CA would report directly to the district and not the research team coordinator. This led to some communication issues and may have undermined the effectiveness of the CA as this may have lead to the perception of being an outside entity performing over the shoulder inspections of district staff.
- *Late start of project compounded some problems* – Time delays at outset of the project caused the CA to come on board after some design work had already taken place. This enhanced confusion surrounding the commissioning process and compounded coordination issues faced by an already busy design team and school staff to accommodate the needs of the commissioning process. It also required the CA to play "catch up" during a critical portion of the design phase and project familiarization.
- *There was little time up front for informal meetings/partnering* – This translated into communication problems later in the process. It was felt that this contributed on more than one occasion to the overall lack of teaming which was observed and/or commented on throughout various stages of the design and construction process.
- *Commissioning specification was published late in the process* – At the conclusion of the study it remained unclear whether this had any direct negative impact on the commissioning process. It is possible that the lack of "up front" knowledge included in the specification may have led many individuals to entertain unclear ideas as to what the commissioning process was to accomplish and the specific areas of responsibility that would be undertaken by the CA. Also, what documentation, per the commissioning specification, would be provided and the specific level of testing and oversight which were in the specification were not made available which may have fostered some of the misconceptions outlined here. This issue was mentioned by several staff/team members at the conclusion of the study.
- *Overall communication was lacking* – This was an observation/comment that was noted throughout the process. It can be attributed in part to other lessons mentioned in this section. Much of this communication concern stemmed from the fact that this was the first commissioning project to be undertaken by the district and that this process was also the subject of this study. This led to confusion which in turn fostered this lack of

communication. As with any new process that is exercised, the communication improves with time and understanding. This is expected to be the case with the commissioning process as well.

- *Some problems were compounded by a very busy staff* – Coordination with school district staff is an important part of the commissioning process. If the building owner is new to commissioning, with an already full workload, many necessary items might be forgotten or left unattended. This is not a fault of any group or agency, but merely an observation of note, since "injecting" a new process into a busy construction program without adequately accounting for increased time in scheduling and coordination will detract from the commissioning process.
- *Initial input into design was a missed opportunity* – This was due to the late start of the commissioning contract which was actually part of the larger study for this project. This did not allow the CA to have input at the initial stages of design which might have benefited the building owner.
- *Onsite tasking was unclear* – There were many inspections and reviews that were done by the CA as well as district staff. Many were overlapping and necessary, but some could be considered redundant. This might have been resolved with communication.
- *Team building was not a priority* – Even with briefings and talking papers provided up front along with hours spent in discussion, key players from all areas never really had time to lay out a roadmap for scheduling meetings, attendance, and facility tasking. This lesson specifically refers to post construction start when communication between the CxA, school district staff, and contractors were critical.
- *Commissioning was perceived as redundant* – This was mentioned on several occasions, as many individuals considered what was already being done as far as inspections and oversight to be sufficient. This stems directly from the lesson mentioned above that a clear understanding of commissioning process and how it differed from existing programs was not adequately addressed. Again, as with any new process there is a learning curve associated with it. This being the first undertaking for commissioning in the school district, there is an expectation that this will improve with time and attention.
- *Design firm was skeptical of the outcome* – This comment is a more specific example of the preceding lesson learned and is an understandably valid concern on the part of any design firm. Competent engineers and architects may not be fully aware of the benefits of commissioning as it currently is practiced. Knowledge may be limited to previous experience which has evolved as the commissioning industry has progressed and expanded. This leads some to believe that there is no benefit gained through commissioning, particularly if the design firm feels that they are already addressing all of the owners concerns.

So in "discovering" these lessons learned there should be some remedies to some of the situations that would possibly mitigate some of these observations. The bullet list below with explanations is appropriate as a starting point for these discussions. These statements cannot be considered all inclusive for this project. There were areas of concern that might not have been identified or comments that were not voiced by staff or on site personnel.

However this does not discount the usefulness of these "recommendations" since they are general enough in nature to provide worthwhile basis for anyone considering commissioning for future new construction and/or major renovation or remodeling of buildings and mechanical systems.

- *Ensure adequate/timely team building occurs between all participants* – This is one of the key components to a successful commissioning program. The building owner should take time up front to allow this to occur since they are directly responsible for hiring/funding the CA. Ideally it should take place in advance of new facility design or renovation when they are in preliminary or conceptual stages. This will allow the CA to provide input into the actual design when it progress to that stage. The owner's staff and the CA need to develop a "team oriented" rapport and become familiar with the skill set that each brings to the project. It is only in this way that the outcome of the commissioning process can be maximized. This serves to circumvent or reduce any concerns that may arise over specific items such as inspections, report writing, and follow up with the design firm or contractor/subcontractor.
- *Draw clear lines of responsibility/action* – This "organizational chart" should be published and distributed prior to start of the design process. This allows the owners staff as well as the contracted design and construction firms to be made aware of where the CA position is with respect to the project hierarchy. It will help to define roles and responsibilities. This chart might contain a subset of duties and responsibilities outlined in the commissioning specification with respect to the CA and can be used repeatedly in meetings and discussions as a visual aid for project participants. It is in addition to and not a substitute for other meetings and discussion which needs to take place between all concerned parties. The position of the CA in the program will vary in each organization by project, and level of expertise within the owner's organization. Ideally, the CA will report directly to someone that has authority over the construction program for the owner. This individual needs to be high enough in the owner's organization, preferably a key decision maker in the organization, that will lend credence to the activities and recommendations of the CA, and which in turn will allow the CA to accomplish necessary project improvement goals. Care must be exercised however that the owners staff does not view the CA as a "hatchet man", or somehow as their immediate supervisor on the job site.
- *Complete/provide commissioning specification early in the process* – This is important in that it would serve to alleviate questions surrounding the commissioning process up front. It would also assist the owner's staff in asking questions of the CA with regard to specific commissioning tasks, responsibilities, and testing and start up of equipment. Even though the CA is considered a skilled professional, the specification is the precursor to the developed statement of work (SOW) and the owners staff need to document work accomplished by the CA based on this or some other documented standard.

- *Explain commissioning early on w/ repeated follow up discussion* – This needs to take place in order to remind people that the CA is on the job and working on behalf of the owner towards successful and on time project accomplishment. The overall goal of commissioning, which is both process and technical improvement, needs to be part of this repeated explanation as well. At some point, this discussion should involve the owners M&O staff responsible for facility maintenance. This will preclude any misconceptions that commissioning is just another inspection and somehow an obstacle rather than a benefit.
- *Engage key players at appropriate levels* – It is important that the building owner invest sufficient time and manpower resources to successfully accomplish the commissioning process. This often entails high level oversight and coordination from upper level management, which due to otherwise busy schedules may not be easily accomplished. As part of developing roles and responsibilities, the owners "share" of the process must also be included. Regular, scheduled meetings should take place to inform about the status of the project and the commissioning aspect as well. This should preclude any surprises in construction scheduling based on foreseeable occurrences and allow decision makers to adjust plans and provide direction to contractors, staff, and the CA.
- *Develop commissioning contingency plan and brief team accordingly* – This type of plan should consider those unforeseen circumstances that are inevitable during large project construction programs. These items relate to that stage of the construction where weather, contractor delays, change order, material back order, and other delays in schedule cause adjustments to inspection and verification tasks. Commissioning professionals and district staff could maximize their resources if a "game plan" was developed in advance of these occurrences which could anticipate delays, and provide plans to adjust the schedule, and most importantly to ensure that important oversight is accomplished as required.
- *Match commissioning activity to construction schedule and facility needs* – This item is partially related to the immediately preceding lesson which deals with contingency concerns. It was noted by participants of the study that flexibility needs to be a key component of the commissioning process. This should be a priority undertaken by the owner's staff and the CA. This ability to adapt to changes in schedule, equipment installation, and other contingencies is necessary if all elements of the commissioning process are to be accomplished in their proper sequence as specified. Continuous discussion between the owner's staff and the CA is relevant to making this happen. Monitoring on site construction activities and the free flow of information between individuals will help ensure a successfully commissioned facility.
- *Communicate* – As always saving the best for last, this element can be described as the cornerstone to a successful commissioning project. As has become apparent from the lessons and responses mentioned above, continuous and pertinent communication might have alleviated many of the concerns voiced by participants of this study. It is the opinion of the study team that the CA, in order to perform at that high level expected by the owner, must take the lead in developing a close working relationship with all members of the owners staff as well as the design team and contractors.

This is a daunting task which can be facilitated by the owner's representative in authority, but can only be fostered by the CA to develop and enhance the proper working relationship necessary for continued support. This is no way places this burden solely on the CA, for as is apparent, communication is a two way street. Design professionals, contractors, and owners must be approachable and willing to allow and accept productive and relevant comments made by the CA.

Commissioning Template

There is no attempt in this document to recreate the voluminous amounts of technical and background material on facility commissioning currently in use throughout the building and construction industry. There are many resources available both on the internet and in publication form for individuals interested in pursuing commissioning related activities either organization wide or on a case by case basis. Many if not all of these documents are provided free to potential commissioning customers. Also, many reputable commissioning firms will provide the majority of detailed resources (specifications, forms, etc.) for review at the customer's request.

A short list of reference organizations which have developed commissioning guidelines and various other documents related to the commissioning industry are listed below.

American Association of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) http://www.ashrae.org/

American Institute of Architects (AIA) http://www.aia.org/

Building Commissioning Association (BCxA) http://www.bcxa.org/

California Commissioning Collaborative (CCC) http://www.cacx.org/

National Clearinghouse for Educational Facilities (NCEF) http://www.edfacilities.org/rl/commissioning.cfm

National Environmental Balancing Bureau (NEBB) http://www.nebb.org/

Portland Energy Conservation, Inc. (PECI) http://www.peci.org/

Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) http://www.smacna.org/

U.S. Green Building Council (USGBC) https://www.usgbc.org/

In addition to those resources listed, there are many state and federal agencies which provide help and support to individuals and organizations planning to implement the commissioning process.

Appendix B of this document provides some background information, and an abbreviated template with an explanation of items to consider when undertaking a commissioning project. This information is provided as a primer with basic considerations for the facility owner or building maintenance professional. This information is not considered all inclusive and is not meant to preclude the documents and guidelines of a professionally accredited commissioning provider. For the novice to building systems commissioning, there is no substitute for checking references and the interview process when contemplating the hiring of a commissioning authority.

APPENDIX A: List of Acronyms

Acronym	*Description*
A/E	Architect/Engineer Firm
AHU	Air Handling Units
AirModel	Simplified system performance simulation program developed at Texas A&M University
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BESL	Brooks Energy and Sustainability Laboratory
CA	Commissioning Authority
CBECS	Commercial Building Energy Consumption Survey
ccf	hundred cubic feet
CCO	Contingency Change Order
CO	Change Order
ECM	Electronically Commutated Motors
EMCS	Energy Management and Control System
EnergyPlus™	System performance simulation developed by the Department of Energy
FCU	Fan Coil Unit
IECC 2000	International Energy Conservation Code
kBtu/sqft	1000 British Thermal Unit per square foot
kWh	kilowatt-hour which is 1000 watt-hours
MBH	Thousand BTU's per hour
MEP	Mechanical, Electrical, and Plumbing
M&O	Maintenance and Operation
Msqft	1,000,000 square feet
NISD	Northside Independent School District
QA	Quality Assurance
RFI	Request for Information
SECO	Texas State Energy Conservation Office
sqft	square feet
TAB	test and balance
WO	Work Order

APPENDIX B: Basic Commissioning Template

Prerequisites to Building Commissioning:

A properly commissioned project requires that the commissioning authority (CA) involved with the project have expertise in many varied disciplines. Some of these disciplines are:

- Coordination
- Communication
- Documentation
- Mechanical systems (air and water side)
- DDC control systems

This combination of skills is rare, and care must be taken to ensure that the selected commissioning agent possess all these skills and more. Past performance (on completed projects) must be reviewed prior to deciding upon which commissioning agent will ensure your project is completed successfully. Consult with facility managers and building owners in your local area to determine if they have any experience (good or bad) with prospective commissioning providers.

Most Common Types of Building Commissioning:

Building commissioning can be carried out under various scopes and contractual arrangements and. Here is a list of the major types of building commissioning that are routinely contracted.

For the Mechanical Contractor
Mechanical Commissioning for the Mechanical Contractor – Actions and reporting are performed under contract to the mechanical sub-contractor. Period of performance is contract tender through to demonstration/startup. Actions performed may be a subset of full systems commissioning.

For the Owner
Mechanical Commissioning for the Owner – Period of performance begins at conceptual design through to full operation and facility turn over. This is considered full systems functional and operational commissioning reporting directly to the facility owner. Commissioning authority has input throughout design and construction. Deficiency reporting is directly to the building owner/manager.

Electrical
Electrical Commissioning – This may be done for the electrical contractor or for the facility owner and is contingent on the scope of the project.

Re-Commissioning
Re-Commissioning – This is actually a misnomer in that many facilities were never commissioned initially. Generally performed for the owner in response to repeated service calls

or equipment and operational problems. This action may also be as a result of higher than normal utility costs for a given facility.

Commissioning Process

There is actually no universal approach used for commissioning. As the benefits of the process are researched and understood to a greater degree, many professional organizations are refining the process to a set of more specific requirements. In the United States, ASHRAE is probably the most widely used reference on the subject and has recently updated its Commissioning Guidelines (2005). These guidelines specifically focus on HVAC (mechanical systems) commissioning which is the most widely utilized in the industry today. Other commonly referred to organizations which provide commissioning guides and information was listed previously in this report.[1]

For reference purposes, other commonly cited documents are:

- HVAC Systems – Testing, Adjusting, and Balancing (SMACNA)
- Procedural Standards for Buildings Systems Commissioning (NEBB)
- Building Commissioning Guidelines (PECI)

As stated above, there is no universally accepted approach to commissioning, and practices and procedures may vary among guidelines. Due to this aspect, professional commissioning agencies may adhere to one set standard as prescribed by their affiliate organization. As a minimum, most commissioning providers follow three general steps as described below.

- Develop Commissioning Plan – the commissioning Authority develops a commissioning plan that includes items such as the project schedule, construction contractor responsibilities, outstanding information requirements, equipment and systems test procedures, monitoring plan, and building operator training.
- Execute Commissioning Tests – The testing activities typically begin with precommissioning or inspection tests to verify that equipment and controls are installed as specified in the design drawings. These inspections are followed by more in depth functional performance tests. Functional tests are intended to determine whether the installed system is adequate, controls are properly calibrated, controls sequences are correct, and proper responses occur to appropriate set points and predefined parameters.
- Operations and Maintenance - The CA reviews the training procedures and O&M manuals to ensure that proper attention is given to specialized equipment and user needs. This may include periodic inspections and tests similar to those performed during commissioning.

For new building commissioning, the earlier the CA is contracted and brought into the picture the more comprehensive and complete the commissioning process. This will allow for the timely scheduling and occurrence of specific testing and verification procedures without causing delays and impacting the overall construction process. It will also allow the commissioning authority to provide input into the project from both a process as well as a technical perspective

[1] See also http://ateam.lbl.gov/Design-Guide/DGHtm/thescopeofcommissioning.htm

from conceptual design through to construction completion. This will provide the building owner with the best overall product that commissioning can deliver.

<u>Goals for Mechanical Commissioning for the Owner (design through to full operation)</u>

The type of commissioning referred to as full scope commissioning (for the owner), which starts at the design stage and continues through to proper training of the operators. Although there are many expectations for the commissioning process, the owner's requirements are paramount.

As a minimum, this type of commissioning (full scope commissioning for the owner) ensures that:

- The project is on time
- The project is within the budget
- The design is proper to meet owners needs
- The systems and sub-systems perform properly
- The operators are properly trained
- The documentation is correct and sufficient

<u>The Commissioning Team Members and their Responsibilities:</u>

A successful commissioning process cannot occur with the CA operating alone. Every party which has a hand in completing the project must contribute to the commissioning process to achieve, in the end, a building which functions to meet the needs of the owner. The roles of these team members must be clearly defined within the contract. These parties are listed below (along with their responsibilities):

All Commissioning Team Members:

- Attend commissioning meetings
- Act promptly on items of work indicated in commissioning meeting minutes
- Work with other team members to derive a realistic commissioning schedule
- Ensure commissioning schedule is maintained
- Provide required documentation promptly
- Cooperate with the other commissioning team members to complete the project as efficiently as possible (this is to everyone's benefit)

Owner's Representative:

- Assign a person to be responsible for overall system knowledge
- Organize personnel to be demonstrated to and trained
- Sign-off "Demonstration to the Owner"

Mechanical Engineer:

- Inspect static completion items (such as seismic restraint, code compliance, maintenance concerns, etc.)
- Ensure static system tests have been performed (such as pipe pressure testing, duct leakage testing, etc.)
- Clarify contractual documents as required (response to RFI's, change orders, etc.)
- Indicate design intent as required
- Sign-off "Demonstration to the Engineer"

Mechanical Contractor:

- Organize own resources and those of sub contractors (suppliers, sheet metal, controls, fire protection, duct cleaning, etc.) to meet the schedule and perform corrective work as required
- Keep informed on commissioning meeting minutes and ensure minutes are responded to by appropriate parties
- Keep the commissioning agent fully informed on all aspects of the project (change orders, supplier delays, scheduling problems, etc.)
- Perform equipment startups (with suppliers as required)
- Operate equipment during tests

Controls Contractor:

- Perform own controls commissioning
- Show commissioning agent control system in sufficient detail to allow commissioning agent to perform his checks
- Coordinate the engineer's approval of a detailed sequence of operation

Balancing Agent:

- Produce independent report to the approval of the mechanical engineer
- Report, to the commissioning agent, problems as they are encountered

General Contractor:

- Organize own resources and those of sub trades (painters, drywall, flooring, millwork, electrical, etc.) to meet schedule and perform corrective work as required

Commissioning Agent:

- Assist mechanical contractor in the overall responsibility for the commissioning of the project as per above definition and contractual documents
- Predict problems before the occur, as is possible, and initiate resolution
- Identify and initiate resolution to problems as they occur
- Derive commissioning schedule and monitor for accuracy
- Hold commissioning meetings and generate minutes
- Witness and document system verifications
- Ensure that documentation is obtained as per the requirements of the specifications
- Coordinate demonstration of systems to engineer and owner
- Issue commissioning report.

The Commissioning Report:

The Commissioning Report contains a historical record of the process of commissioning. It is useful as a final verification document, as a starting point for eventual re-commissioning activities. Another consideration is that the report can even prove to be an important asset when future plans for renovation and/or building additions are being planned.

The Commissioning Report can be explained by describing the various pieces of documentation which it contains. This documentation is described below.

Summary Commissioning Item List
This list is an all-inclusive list of outstanding concerns at the time the report is issued. These items are cross-referenced into the checkout sheets listed below.

System Checkout Sheets (Point and Functional Verification Sheets)
These sheets pertain specifically to the various systems on the project. Depending on the background of the CA, documentation sheets may take on various forms and formatting styles. It is important to note that these sheets should contain as a minimum the information as outlined recognized/accredited commissioning organizations in your area. Many of these forms have been standardized. It would also be helpful to request as attachments to any proposed Statement of Work (SOW) copies of any forms to be used by the CA in performing their activities.

System Checkout Sheets are generally divided into the following three main sections which are described below:

Identification and Data Section
Tag, Make, Model, etc.

Checkout Items Section
The checkout items are specific checks to be made. These checkout items are of two main types depending of whether the System Checkout Sheet is subtitled Functional Verifications or Point Verifications.

- Functional Verification Checkout Items are the specific functional checks which were performed. These items are in accordance with the approved sequence of operation and as per the design intent.
- Point Verification Checkout Items are the system point checks of the four types (analogue in and out and digital in and out).

Checkout Notes Section
The checkout notes section is where numbered notes or deficiencies are recorded. These checkout notes are referenced from the "Note" column of the checkout item section above.

Equipment Checkout Sheets
These sheets pertain specifically to the various pieces of equipment on the project. Equipment Checkout Sheets are divided into the following three main sections which are described below:

Identification and Data Section
Self explanatory.

Checkout Items Section
The checkout items are specific equipment checks to be made. These checkout items are divided into three categories, which are:

- Pre-start Checks
- Startup Checks
- Adjustment Checks

Note that some checkout items indicated on the Equipment Checkout Sheets are for the contractor to certify. These checkout items are either not verifiable by the commissioning agent or they are the work of other contractors. Examples of such Equipment Checkout Items are:

- Unit has been properly lubricated
- Setscrews and fasteners have been tightened

Checkout Notes Section
The Checkout Notes section is where numbered notes or deficiencies are recorded. These checkout notes are referenced from the "Note" column of the checkout item section above.

Other Documentation
Certification letters, sign-off letters and miscellaneous reports and certificates as required.