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ENERGY AUDIT AND SIMULATED CONSERVATION OPPORTUNITIES FOR A RENOVATED MIXED-USE ACADEMIC BUILDING

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ABSTRACT

This paper describes an energy audit performed in a 97,760 ft^2 (9082 m^2) academic building at the University of Texas at San Antonio (UTSA). The paper describes the building survey and a simulation of the building's energy use using eQUEST software calibrated with monthly and hourly utility data. Conclusions of the survey identified problems with the building envelope, indoor air quality, and HVAC controls which were promptly addressed. Nine longterm energy conservation opportunities (ECOs) were identified and evaluated. Five ECOs related to lights, envelope, and HVAC were recommended with a total implementation cost of $165k. It is shown that a savings of 23.7% in overall energy usage can be achieved with a payback of less than 8 years. In addition to energy and economic savings, building performance and occupant comfort are expected to improve.

INTRODUCTION

A building energy audit can be defined as a process to evaluate where the building uses energy, and subsequently identify existing opportunities to reduce the energy consumption (Thumann, A. & Younger, W., 2003). The purpose of this study was to conduct a detailed energy audit of the Monterrey building in the University of Texas at San Antonio's (UTSA) Downtown Campus,. This level three audit included a detailed analysis of the building's energy use by function and a comprehensive evaluation of energy use patterns. This was accomplished by conducting a building survey followed by a calibrated simulation of the energy use. The project represented a collaborative effort between UTSA's Office of Facilities, the Department of Architecture, and the Department of Mechanical Engineering. The project allowed students from both departments to be employed by the office of facilities to conduct the audit under the supervision of faculty from both departments. This allowed the students to gain valuable experience, while providing a needed and important service to the university.

The Monterey building, with a gross floor area of 97,760 ft^2 (9082 m^2), was originally built in 1984 as an commercial facility. It was purchased by UTSA in 2005 and after several renovations and retrofits, currently houses the College of Architecture and other university departments. There are two distinct structures that make up the Monterey building, (1) a 67,500 ft^2 (6273 m^2) four-level office building (hereafter referred to as "tower"), originally designed as commercial office space, and now used for faculty and staff offices and several large design studios, and (2) a 30,230 ft^2 (2808 m^2) single-level industrial warehouse (hereafter referred to as "annex"), originally designed as a manufacturing/distribution center, and now used for design studios, computer labs and additional offices. This radical change in function, from commercial to educational, resulted in a variety of energy performance issues. These issues, along with the dated systems used in the building, whose maintenance prior to UTSA acquisition was undocumented, made the Monterey building a prime candidate for this project.

The project included conducting a detailed survey of the building envelope, lighting and electrical systems, HVAC systems, and other miscellaneous systems in the building. A thermal imaging survey of both buildings and a recording of internal conditions in key areas in them using data loggers was also conducted. The survey results were used to identify problems requiring immediate attention as well as no-cost/low-cost energy conservation opportunities in the building, then formed the basis for a whole-building energy

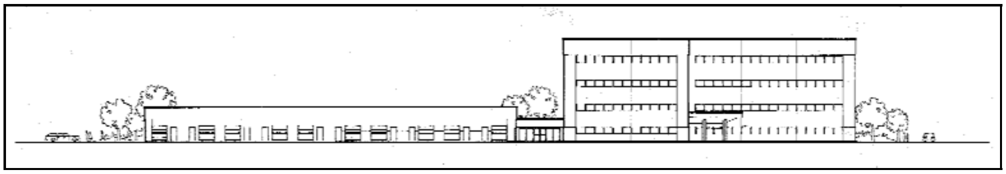


Figure 1. South Elevation View of Monterey Building

simulation model developed using eQUEST v3.6 (Hirsch, 2006), and calibrated using utility bill data for the last 24 months as well as 6 months of hourly building electricity usage data obtained from the local utility. The results obtained from the calibrated model formed the basis for a detailed life cycle cost analysis of energy conservation opportunities in the building. The outcome of the project consisted of a detailed report which was presented to the university administration with the aim of identifying funding sources for implementing its outcomes.

THE SURVEY PROCESS

The first task of the energy audit included a survey of the building envelope, lighting and HVAC conditions. Several survey forms were created to record the information. The forms were adapted from Washington State University's Energy Program (Washington State University, 2003). A general building form, a building space survey form, and an HVAC survey form were used. The information collected during the survey included details of the building envelope, lighting, plug loads, and occupancy patterns. Measurements of temperature, CO_2 concentration, lighting levels and humidity in typical building spaces were also collected using data loggers, and thermal images were also captured for key areas of the building envelope.

For the HVAC system, a thorough survey was conducted of the systems in both the tower and the annex. The survey included measurements of power quality, air and fluid flow, electric current, among others. The survey results were documented using the developed forms and, along with the space survey results, formed the basis for the simulation model.

Building Envelope Overview

Tower.

The main construction system in the tower is a 30 ft (9 m) steel frame system. The exterior walls are light gauge steel construction with 3.5" (0.088 m) of batt insulation and an effective R-value of 9.6 h•ft^{2}F/Btu (1.69 K.m^2/W). Exterior windows are 6 mm single-pane, tinted glass, with metal frames. The center of glass U-value is 1.09 Btu/hr.ft^2.F (6.17 W/m^2.K) and the window to exterior wall percentage ranges between 19% and 20%. The roof has 3" (0.076 m) of rigid polyurethane sheets with an effective R-value of 17.5 h•ft^{2}F/Btu (3.08 K.m^2/W). The lighting system consists of recessed fixtures with 4' (1.2 m) T-12 florescent bulbs and a mixture of electronic and magnetic ballasts.

Annex.

The construction system in the annex is light gauge steel studs at 24" (0.6 m) o.c.. The wall, roof, and window construction is identical to the tower. While the window to wall ratio in the annex is significantly smaller than the tower (ranging between 8% and 12%), the annex has a large number of uninsulated metal doors, which significantly affect the thermal performance of the building. The lighting system consists of industrial suspended fixtures with 8 ft (2.4 m) T-12 florescent bulbs.

HVAC System Overview

Tower.

The all electric mechanical system in the Tower consisted of a single-duct, variable air volume (VAV) system with cooling supplied by two 1.56 MBtu/h (457 kW) chillers, and heating supplied by perimeter zone electric reheat coils with parallel booster fans. The air distribution is accomplished by two 576,000 Btu/hr (169 kW) air-handlers (AHUs) that supply approximately 16,000 cfm (7.55 m^3/s) each. Outside-air (OA) is supplied by a large intake louver located in the mechanical room. (Control of the OA intake was non-existent at the time of the survey and the control damper remained at 0% blocking intake of OA). Return air flowed through the plenum and was not fan controlled. Only perimeter zones had electric reheat coils included in the VAV box, which supplied heat to the space with a parallel booster fan. Core zones had no heating capacity and relied on the perimeter zones for heating. The controls for the system are all pneumatic and the thermostats are all reverse-acting. The pressure in the pneumatic system is maintained by a dual motor air compressor. The AHUs are controlled by variable frequency drives (VFDs). The design of the system was based on the original open plan design (Figure 2a). Subsequent architectural modifications, following the building's purchase by UTSA (figure 2b), which added a large number of interior partitions to the building, did not include any HVAC system modification to accommodate the new situation. This results in poor system control and a large number of user complaints.

Annex.

Annex cooling is supplied by the same chilled water loop that feeds the tower; which split off into two branches: one feeding the Tower AHUs and the other going to the Annex to feed twenty-two 48,000 Btu/h (14.1 kW) ceiling-mounted, single-zone, fan-coil units with electric reheat coils. In addition, the annex also has six 36,000 Btu/h (10.6 kW) DX units. These units did not provide any heating or OA intake. The controls for all systems were pneumatic, other than the six DX units which used electric thermostats. There is no OA intake in the Annex and return air was fed directly. Similar to the Tower, the renovations of the Annex, which also added a large number of interior partitions to the original open plan design, resulted in poor system control. In the case of the Annex this included duct branches being added to serve small spaces, spaces with no air return air inlets, and spaces being served by multiple units each with its own thermostat.

Survey Results

In addition to identifying existing ECO's (as will be discussed in the following section), the survey also identified a number of existing issues with the building envelope and HVAC systems. These issues played an important role in determining which ECO's were evaluated using the calibrated simulation. These issues can be summarized as follows:

Indoor Air Quality.

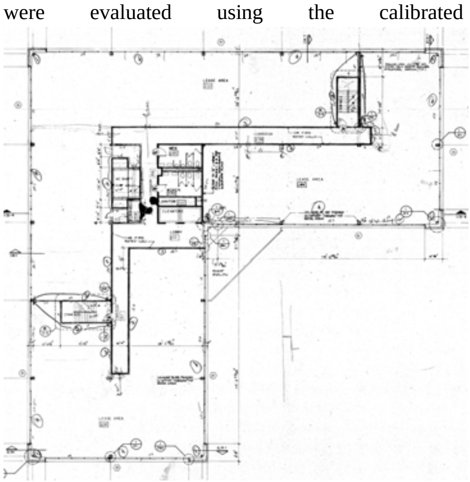
Measurements of CO_2 levels in typical studios and class rooms showed CO_2 levels as high as 2000 ppm during periods of high occupancy, only dropping down to approximately 1000 ppm after several hours at no occupancy. This was compared to outside CO_2 measurements, which were between 400 and 600 ppm, thus indicating low air change rates in parts of the building.

Building envelope.

In addition to issues determined from observation and drawings, thermal imaging showed several additional problems. Some of these problems included missing insulation in the upper parts of all annex exterior walls (see Figure 3), severe thermal bridging around exterior doors and windows, especially the overhead doors in the annex, and lack of proper insulation around pipes and ducts. This information was later used in the model calibration phase of the project.

Lighting.

The survey identified several issues regarding the lighting system including (1) use of inefficient bulbs and fixtures, (2) low illumination levels in the building with some areas having an illumination level of 20 foot-candles or less, and (3) lack of lighting controls, resulting in large areas having all their lights on, often continuously, when they were either unoccupied or had very low occupancy.



2a. Original Open-Plan Space Layout

2b. Existing Space Layout (After Modificaitons)

Figure 2. Space Layout of the Tower Building Before and After Architectural Modificaitons

Figure 3. Thermal Image of Annex Studio
(Note: Thermal image taken during cold weather)

HVAC Controls.

The Monterey building controls are primarily pneumatic. When properly set-up and maintained, pneumatic controls can be an effective means of controlling an HVAC system. However, changes in building function since acquisition by UTSA have resulted in several control problems. Some of the major problem included the thermostats, control valves, control system air leakage, erratic or improper heat activation and the inaccuracy or non-existence of controls in many areas. The survey showed that existing controls, especially in the annex, are not effectively controlling the HVAC system and that large quantities of energy were being lost as a result. These losses were clearly evident in the average daily monthly load profiles, generated for the annex from the hourly utility data, which were predominantly flat and showed no noticeable daily, weekday/week end, or seasonal variation (see figure 4a & b).

Incomplete Renovations.

The Monterey building required several renovations to meet the needs of the University. However, the survey showed that in general, mechanical systems often were not adapted to the new spaces. In several areas a renovation project consists of adding interior partitions to redefine spaces and resize offices. The situation resulting from this retrofit included diffusers located on top of walls, spaces not receiving the proper amount of air, improper location of thermostats, ducts being disconnected from diffusers, and spaces being served by multiple units (up to 8 units in one annex space) each with their own thermostat.

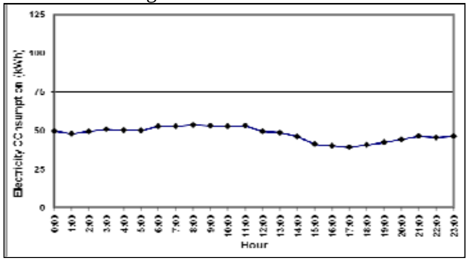
Utility Data Analysis.

Analysis of the hourly utility data, showed significant trends in building energy consumption. The identified issues included: generally low power factor especially in the Annex (as low as 0.7), very high night and weekend (base) demand in both buildings (up to 120-150 kW or 1.8-2.2 W/ft2 for the tower), and an unexpected, almost flat, load profile for the annex.

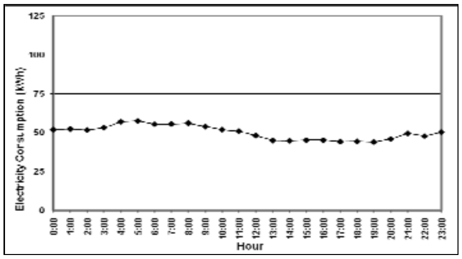
MODEL DEVELOPMENT, SIMULATION, AND CALIBRATION

Figure 5 shows a screen-shot of the Monterey building model, which was developed using the DOE-2.2-based simulation software eQUEST® (Hirsch, 2006) . The simulation process started with the Design Development Wizard and used existing AutoCAD drawings of the building. The building was modeled as five separate shells, one for each of the levels of the tower and one for the annex. To account for multiple units serving the same space in the Annex, separate zones were created for each fan-coil and DX unit.

Following the development of the initial model in the Design Development wizard, the model was further modified in eQUEST's detailed mode to reflect the detailed information obtained from the building and system surveys. In this phase, eQUEST software defaults in occupancy, scheduling, internal loads, and HVAC system were replaced with more accurate survey data. This included developing detailed schedules for typical spaces within the building and assigning more accurate occupancy and load data. HVAC system details were also modified to reflect the existing situation.



4a. Annex Average Weekday December Load Profile



4b. Annex Average Weekend March Load Profile

Figure 4. Annex Average Daily Monthly Load Profiles

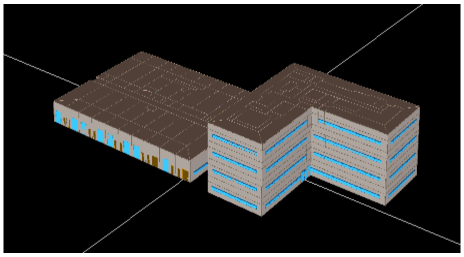


Figure 5. Screen-Shot of eQUEST® Model

After a satisfactory baseline model was created in the detailed mode, the model was calibrated using 12 months of utility billing data and 6 months of hourly data obtained from the local utility for each of the two buildings (tower and annex). Several eQUEST calibration runs were performed, which included modifications to infiltration rates, lighting loads, outside air ratios and schedules (to account for periods during the survey with no outside air intake), glazing types, thermostat heating and cooling setpoints, and occupany (and other related) schedules. The calibration process was performed seperately for each of the two components of the Monterey building (tower and annex) and initially aimed to reduce the difference between the actual and simulated annual energy usage to between 3-5% and the difference between the actual and simulated monthly energy usage to between 5-10%. Figure 6 shows the combined simulated energy consumption by end use for the Monterey building (tower and annex).

The results of the calibration compared well with the monthly utility data. For the tower, the calibrated model resulted in an energy use index (EUI) of 20.85 kWh/ft^2.yr, a difference of only 0.1% from the actual EUI of 20.88 kWh/ft^2.yr (calculated from the utility data). Monthly differences between simulated and

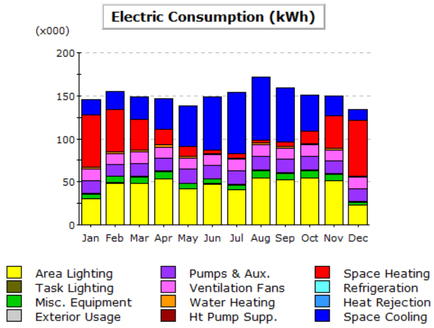
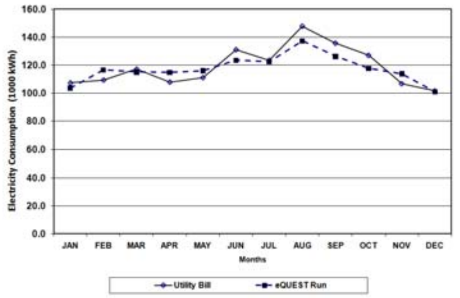


Figure 6. Simulated Monthly Energy Consumption by End-Use

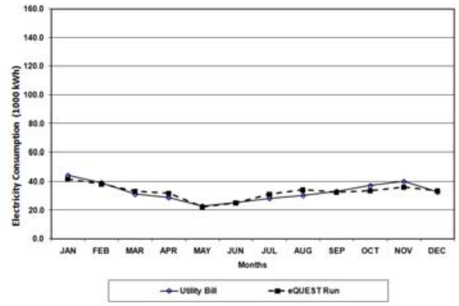
actual energy usages for the tower ranged from -8% to + 6% (see figure 7a). For the annex, the simulated EUI was 13.01 kWh/ft^2.yr, a difference of 3.5% from the actual EUI of 12.56 kWh/ft^2.yr. Monthly difference for the annex ranged from -10% to +9% (see figure 7b). The calibration process for the annex proved more difficult due to the control issues discussed previously.

EVALUATION OF ENERGY CONSERVATION OPPORTUNITIES

Both the survey and the simulation results were used to identify a number of possible ECOs in the building. These can be categorized into three main groups: lighting system modificaitons, HVAC system modifications, and envelope modifications. The potential for lighting system modifications was evident from the survey and was confirmed by the simulation result, which showed a significant contribution from lighting to the overall energy use (see figure 6). Based on this, several modifications to the lighting system were considered including replacing existing T12 bulbs with the more efficient



7a. Tower Simulated and Actual Monthly Energy Consumption



7b. Annex Simulated and Actual Monthly Energy Consumption

Figure 7. Actual and Simulated Monthly Eneryg Usage for Monterey Building

T8s and installing occupancy sensors in educational and circulation spaces in the buildings to reduce lighting energy use (which was identified as one of the primary causes of the high base-demand in the building). Similarly, the potential for several modifications to the HVAC systems were evident from both the survey and the simulation results. The measures evaluated in this case included replacing the dated annex fan coil units with more efficient DX units, replacing the existing HVAC system pneumatic controls with electronic ones, which will allow for enforcing a night-time temperature set-back policy for all thermostats in the building, as well as replacing existing pumps with more efficient VFD ones. Finally, several envelope modificaitons were considered including replacing the single glazed metal windows with double glazed units, replacing the annex overhead metal doors, adding thermal insulation to annex walls, and adding a suspended ceiling to the annex studios.

Both the energy savings and economical performance of each of these ECOs were evaluated. Energy savings were determined by modifying the simulation model to account for the suggested modification and calculating the resulting reduction in annual energy use compared to the base-line calibrated case. The economic performance, on the other hand, was evaluated by performing a life cycle costs analysis (LCCA) to calculate the discounted payback period for each of the proposed measures.

The calculation was conducted using constant 2008 dollars and assuming a discount rate of 3% (typical for UTSA projects). Initial and O & M cost assumptions for the suggested measures were primarily based on RSMeans Mechanical and Electrical Cost Data (RSMeans, 2002) and modified by adding an additional 50% to account for actual overhead experiennces in similar projects at UTSA. Serivce life estimates of equipment were based on ASHRAE reccomendations (ASHRAE, 2003).

No income tax or investment tax credits were included in the evaluation. Enery costs were based on existing local utility cost schedules (CPS, 2005a & b) and did not account for any future increases in electricity charges. It is worth noting here that the local utility has considerably increased its fuel adjustment rate starting in July 2008 to account for increasing oil & gas prices. This rate increase, while not included in the evaluation here, would further improve the economic performance of the ECOs identified in this paper. Table 1 shows a summary of the all the evaluated ECO's, their estimated initial costs, and the resulting annual energy savings, annual costs savings, and discounted payback periods for each.

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Table 1. Analysis of Individual Energy Conservation Opportunities

ECO #	Description	Initial Cost	Annual Energy Savings (kWh/yr)	Annual Economic Savings ($/yr)	Discounted Payback Period (yr)
ECO1	Replace T12 fluorescent bulbs with T8	$75,600	60,736	$3,785	31
ECO2	Install lighting occupancy sensors	$18,340	168,749	$9,239	3
ECO3	Replace Single-pane Windows with Double Glazed	$406,000	29,433	$2,181	> 50
ECO4	Remove annex overhead doors	$13,400	12,882	$545	46
ECO5	Add Suspended Ceiling to Annex	$98,000	16,983	$923	> 50
ECO6	Add thermal Insulation to Annex Walls	$11,620	4,182	$-118	> 50
ECO7	Replace Annex HVAC system with DX units	$138,600	58,430	$3,302	> 50
ECO8	Enforcing a night-time temperature setback policy	$42,000	220,876	$10,391	5
ECO9	Replace existing Pump with VFDs	$16,100	104,386	$6,026	3

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RECOMMENDED ENERGY CONSERVATION OPPORTUNITIES

Based on the resulting performance of the identified ECOs (in terms of both energy savings and discounted payback period), a group of ECO's were identified as feasible (as shown in Table 2). The selected measures included all suggested lighting system modoficaitons as well as most of the suggested HVAC system modification (except for replacing the fan coil units with DX units which was shown to have a considerably high payback period). While none of the suggested envelope modifications resulted in a reasonable payback period, the metal overhead doors replacement measure was included in the final group of reccomended measures because of its low initial costs and potential positive impacts on the indoor environment (the large metal doors resulted in significat thermal discomfort for studio users)

The combined effect of the selected measures was then simulated using eQUEST and the resulting energy savings and economic performance was evaluated using the same methodology described in the previous section. The recommended ECO's, with combined initial costs of $165,440, were shown to result in annual energy savings of more than 420,000 kWh (representing energy savings of 23.7%). The resulting annual cost savings will be $22,860 (representing savings of 19.1% of the building's annual utility cost) with an overall discounted payback period of less than 8 years. The cost savings are due to reductions in both energy use and demand costs.The resulting energy savings and economic performance of the selected measures are shown in table 2.

SUMMARY AND CONCLUSIONS

This study involved performing an energy audit for UTSA's Monterey building. The audit included a survey of the building envelope and systems as well as a simulation of the building's energy use. The simulation model was calibrated using monthly and hourly utility data, and the energy use resulting form the calibrated model compared well with the utility data resulting in a difference in annual EUI of 0.1% and 3.5% for the tower and annex components of the building respectively.

Nine ECOs were identified based on the survey and the simulation results, including lighting system, HVAC system, and envelope modifications, and both the potential energy savings and discounted payback period for each were calculated. Based on this, five ECOs, resulting in good energy savings and low payback periods, were identified and their combined energy and economic savings were calculated. The study concluded that implementing the five reccomended ECOs, with a combined initial cost of $165K, will result in savings of 23.7% in annual energy usage, 19.1% in annnual utility costs, and a discounted payback period of less than 8 years.

Recommended changes in lighting system, HVAC controls, and building envelope will also result in significant improvements in the quality of the indoor environment in the building and therefore increase user satisfaction and reduce user complaints. This represents an additional benefit to the UTSA facilities department in terms of reducing the demand for the maintenance personnel.

These selected ECO's formed the bases for the recommended measures presented to UTSA's facilities department and the facilities department is currently in the process of obtaining the necessary funds to implement these recommended measures.

Table 2. Reccomended Energy Conservation Opportunities

<table>
<tr><th>Group</th><th>ECO #*</th><th>Description</th><th>Energy Savings (kWh/yr)</th><th>Economic Savings ($/yr)</th><th>Payback Period (yrs)</th><th>Initial Cost</th><th>Discounted Payback (yrs)</th></tr>
<tr><td>Lights</td><td>ECO1</td><td>T8 bulbs</td><td rowspan="2">200,543</td><td rowspan="2">$11,845</td><td rowspan="2">10</td><td rowspan="5">$165,440</td><td rowspan="5">8</td></tr>
<tr><td></td><td>ECO2</td><td>Occupancy sensors</td></tr>
<tr><td>Envelope</td><td>ECO4</td><td>Remove overhead doors</td><td>12,882</td><td>$545</td><td>46</td></tr>
<tr><td>HVAC</td><td>ECO8</td><td>Temperature set-backs</td><td rowspan="2">209,324</td><td rowspan="2">$10,470</td><td rowspan="2">7</td></tr>
<tr><td></td><td>ECO9</td><td>Pump VFDs</td></tr>
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* For more detailed discription of ECOs, please refer to table 1.

ACKNOWLEDGMENTS

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