Saving Energy and Improving Comfort at Boeing

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ABSTRACT

When the Boeing Company purchased a 20-year-old building to expand its operations in the Houston area, it found itself in a situation that is all too familiar to many organizations—aging mechanical equipment with outdated controls, rising energy bills, comfort issues, and no magic pot of money to fix everything that needed to be fixed. By carefully focusing their efforts on programs with the greatest payback, they were able to cut their energy usage by approximately 24 percent, over 2 million kWh in the first year of their energy initiative. By continuing to fine tune their energy program, they cut energy use by an additional 9 percent in their second year. Equally important, they improved the indoor working environment and comfort while making these changes and saved the equivalent of 2,037 metric tons of carbon dioxide in greenhouse gas emissions over this same period. This facility received an Energy Star certification and has been submitted for LEED EB certification. This article will examine some of the ways in which Boeing achieved these remarkable results. It will also focus on the reporting tools used to measure both energy use and the indoor working environment to insure the energy savings were not achieved at the expense of lost comfort and productivity.

BACKGROUND

Boeing's Bay Area Boulevard building is a 399,000-square-foot (37,000 m^2) facility located near Houston, Texas. The 1,500 people who work there support NASA's International Space Station and space shuttle programs, as well as other projects related to the exploration of space. The building was originally built for IBM in 1985, and Boeing purchased the facility in October of 2004.

When Boeing acquired the facility, the HVAC equipment was primarily controlled by pneumatics. The pneumatic control system was overlaid with a computerized building automation system (BAS) that provided monitoring, unit start/stop, and limited control functions. Mechanical equipment, particularly the outside air handlers and exhaust units, exhibited the type of wear commonly seen in 20-year-old equipment, with problems like torn flexible connectors and duct leakage. The lighting system was not connected to the building automation system. The indoor environment was similarly typical of a 20-year-old system, with uneven temperature control and ventilation throughout the facility.

ENERGY RETROFITS—2007

A significant energy management upgrade was initiated in 2006, with the upgraded systems coming online at the end of 2006 and beginning of 2007. The building envelope and most major mechanical systems were not upgraded; however, the two outside air handlers and exhaust units were replaced with energy recovery units incorporating enthalpy wheels. Pneumatic control systems throughout the building were replaced with a fully integrated, web-based direct digital control (DDC) system. Thirteen existing VAV air handling units were retained; however, they received new DDC controls plus general maintenance, such as replacing torn fan boots. Similarly, 342 existing VAV terminal boxes were upgraded with DDC controls. The central chiller plant, with three 750-ton chillers and a three-cell cooling tower, was totally converted to DDC control, as were 49-fan coil units and several small single zone units. An automated lighting control system that utilizes a telephone override feature was installed and integrated with the new DDC building automation system; however, this work was not completed until December 2007, so most of the energy savings were not realized until 2008.

ENERGY MANAGEMENT STRATEGIES—2007

The new DDC system and outside air units allowed several new energy saving strategies to be implemented in 2007:

Learning Adaptive Optimal Start

During unoccupied periods HVAC systems are turned off unless rooms become so hot or cold that the system needs to cycle on for a brief period to prevent damage to the building. During this time the DDC system is constantly monitoring the outdoor and indoor air conditions and calculating how long it will take the system to bring the rooms back to comfortable conditions. The system will remain off for as long as possible and automatically turn on just in time to bring the space temperature to the programmed setpoint by the time the space is scheduled to be occupied. The system is constantly learning and tuning itself to calculate the correct start time each day.

Demand Controlled Ventilation

The outside air dampers at each VAV air handler are modulated to ensure that enough outdoor air is brought into the building to maintain comfort and health conditions, based upon measured CO_2 levels. Energy consumption is minimized by not bringing in more outside air than is needed; however, the dampers are opened whenever the enthalpy of the outside air is low enough that it takes less energy to cool it than it would take to cool the return air. Additionally, extra outside air is brought in each morning to purge the building of any chemicals used for cleaning the night before. The use of DDC controls and VFD fan drives on the outdoor AHUs improves the efficiency of the demand-controlled ventilation as it allows the outdoor AHUs to adjust their fan speed to meet the needs of the VAV AHUs they are supplying.

VAV AHU Static Pressure Reset

The DDC system monitors the position of all VAV dampers and modulates the static pressure setpoint of each VAV AHU so that the "worst case" box supplied by that AHU is 85 percent open. If the cooling load in the zones drops and the dampers begin to close, the VAV AHU will slow down its fan in response. This saves fan energy and reduces losses through duct leakage; it also reduces noise.

VAV AHU Cold Deck Reset

The DDC system monitors the demand for cooling in all VAV zones and resets the VAV AHU cold deck setpoint from 53°F degrees to 58°F as the need for cooling drops. This reduces the cooling load on the chiller plant and also helps prevent the use of electric reheat at the VAV boxes.

Chilled Water Differential Pressure Reset

Similar to VAV static pressure reset, the DDC system monitors the position of all the chilled water valves in VAV AHUs and fan coil units and modulates the differential pressure setpoint of the chilled water pumps to keep the worst case valve 90 percent open. Reducing the differential pressure saves pump energy when the demand for cooling is low.

Chiller Plant Low Load Control

This control strategy allows the chiller to cycle on and off under low load conditions, using the chilled water piping system in the building as a thermal storage vessel. This saves energy by not requiring unneeded areas of the building to be cooled to provide a base load for the chiller. (This was implemented as an interim solution, with the installation of a more efficient pony chiller being installed in November of 2008 as a long range solution.)

VAV Box Balancing and Duct Repair

Changes over the years in room use and occupancy, along with the installation of new duct taps and VAV boxes, had seriously upset the system balance. The system was rebalanced to match the current cooling needs. Also, many duct leaks were discovered and repaired during this work. The work was completed at the end of 2007, so most of the energy and comfort improvements were not apparent until 2008.

Fan Coil Unit Fan Cycling

The supply fans on numerous fan coil units that serve unoccupied areas are cycled off when the space temperature is between the heating and cooling setpoints. This saves fan energy compared to the previous control strategy of running the fans continuously.

Overall System Management

The building automation and reporting systems that were installed with the new DDC controls provide constant monitoring of the building operations, including occupancy times, utility consumption, and occupant comfort. This makes it easy for operators to identify problem areas, correct any errant schedules that cause systems to be running when they are not needed, and otherwise "fine tune" the building for maximum efficiency.

ENVIRONMENTAL INDEX

The primary goal of any building system—HVAC, Lighting, Roof, Fire Alarm, etc.—is to provide a safe, comfortable, and healthy environment for the people who work inside the building. Many of these systems consume energy, and it is very important to minimize this energy use; however, it is absolutely essential that this reduction does not adversely affect the people who work inside the building. If, for example, the demand-based ventilation algorithm had reduced ventilation too much, the increased health risk and lost productivity due to uncomfortable workers would have far outweighed the energy savings. Boeing recognized the importance of maintaining the indoor environment and implemented an environmental index (EI) to keep track of this key factor. The environmental index is a rating system that compares each individual zone's temperature, humidity, and CO_2 levels to their respective setpoints. Individual zone indices are "rolled up" into area and total building environmental indices to monitor the overall quality of the indoor environment and give it as much visibility as the energy consumption. Figure 1 shows a system graphic from the BAS that presents the overall energy use and environmental index at the top, with indices for each individual floor shown underneath.

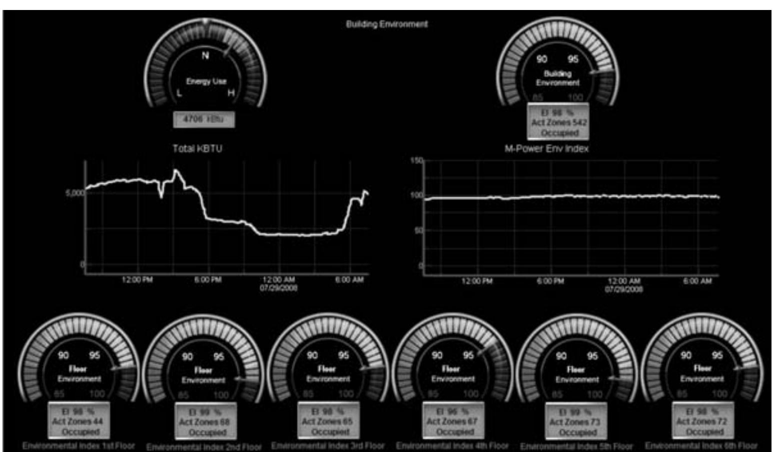

Figure 1. Energy and Environmental Index

RESULTS—2007

The energy management strategies implemented in 2007 resulted in an annual energy savings of 2,026,194 kWh compared to 2006 (Figure 2). According to the U.S. Climate Technology Cooperation Gateway [1], this is the equivalent of 1,424 metric tons of carbon dioxide. In everyday terms, this is the equivalent of the annual greenhouse gas emissions from 266 passenger vehicles or the emissions resulting from the electrical consumption of 202 homes.

Because there was no way to measure the environmental index before the DDC building automation system was installed, there is no way to calculate a 2006 baseline for the EI or to provide "before and after" comparisons of the indoor environment. However, the EI was constantly monitored after the DDC system and the new energy management strategies were in place, and the EI consistently remained in the high 90's on a 0-100 point scale. This confirmed the occupants' perception that comfortable conditions and ample ventilation were being maintained throughout the occupied hours and that the indoor working environment was not being sacrificed for the sake of energy conservation.

ENERGY MANAGEMENT STRATEGIES—2008

The energy initiatives implemented in 2007 continued to provide savings in 2008, and in particular the impact of the VAV box balancing and the automated lighting control system was mostly seen in 2008,

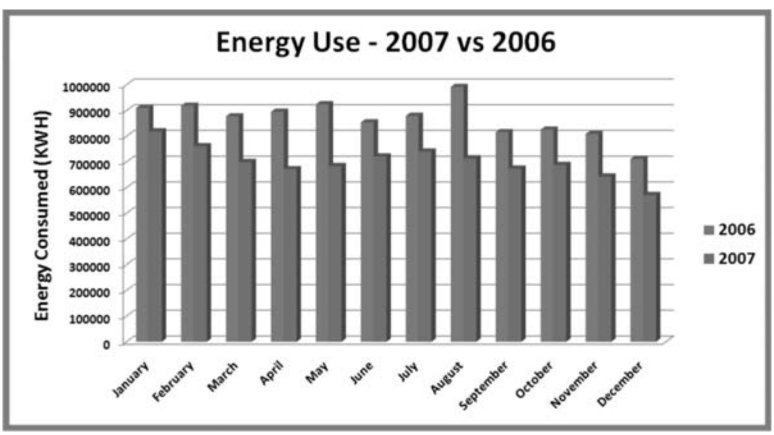

Figure 2. Energy Use 2007 vs. 2006

because the projects were completed late in 2007.

In addition to refining and continuing the strategies implemented in 2007, two new initiatives were implemented in November of 2008:

Replacement of One Existing Chiller

One of the 1984 vintage 750-ton centrifugal chillers was replaced with a new, 290-ton chiller with frictionless magnetic bearings. The reduction in capacity was possible because of the overall improvements in energy efficiency throughout the building, and the smaller chiller was much more efficient for use during low load conditions. For example, the old chiller had a maximum efficiency of 0.6 kW/ton, while the new chiller can operate at 0.33 to 0.36 kW/ton. The new chiller can also be cycled more frequently to meet low load conditions, a feature which is particularly useful when coupled with the strategy that uses the building piping for thermal storage. Some indication of the improvement in low load cycling efficiency can be gleaned from the fact that the new chiller has an inrush current at start-up of one amp versus the over 600-amp inrush current when the older 750-ton chiller is started. The new chiller was installed in November 2008, so most of the annual savings will not be realized until 2009.

Installation of Tower Isolation Valves

In November 2008, isolation valves were installed in the cooling tower system so that each of the three tower sections could be operated independently. The tower sections were originally designed so that each section could handle the load of one chiller, but they ran off a common header such that all three sections operated together. That meant that if one chiller was running, all three tower sections and all three cooling tower fans had to run to meet the needs of this one chiller. Now the sections can be run independently, so if the cooling load is low enough that only one chiller needs to run, the cooling tower can run one section and save the fan horsepower previously used to run the other two sections.

RESULTS—2008

Energy use declined significantly in 2008, with total energy use for the year being 2,835,955 kWh below the 2006 baseline. The combined energy savings for 2007 and 2008 are 4,862,149 kWh. The monthly figures show significant improvements over the 2006 and 2007 numbers (Figure 3). Since many energy initiatives were implemented throughout 2007, the biggest savings of 2008 compared to 2007 occurred early in the year, when the full range of 2007 initiatives were in place. Significant savings are also visible in November 2008, when the new chiller improvements were brought on line.

Cumulative annual energy consumption is shown in Figure 4. The ever widening gap between the 2006 figures and the 2007 figures

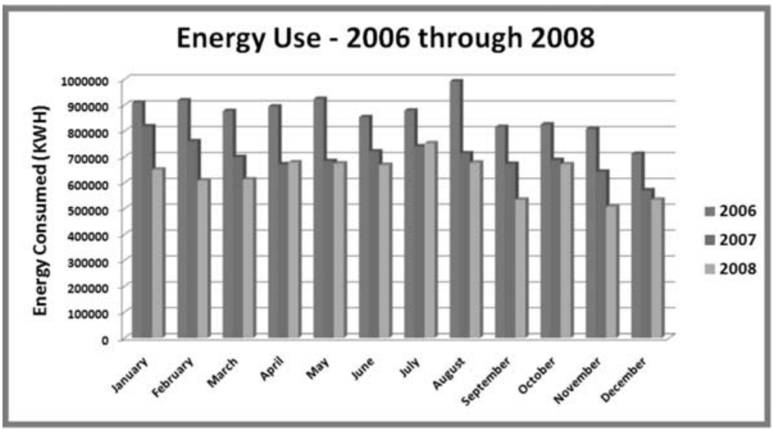

Figure 3. Energy Use 2006 through 2008

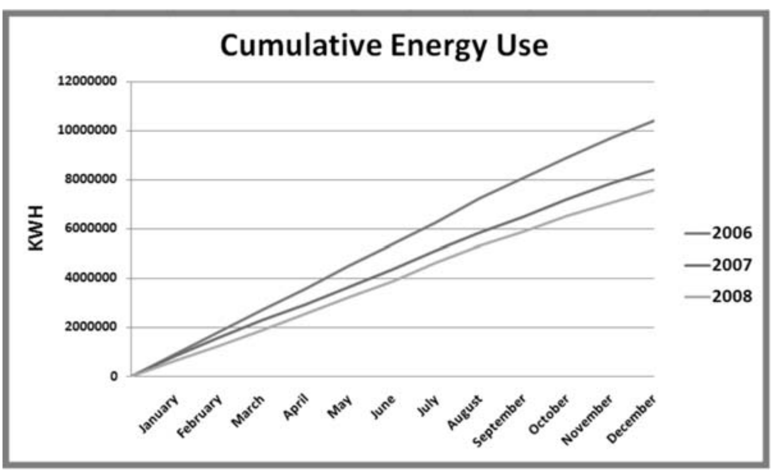

Figure 4. Cumulative Energy Use

shows energy savings increasing as additional initiatives were brought on line. The 2008 trend line shows how these initiatives continued to save energy throughout 2008, with additional savings coming on line in November 2008.

The energy savings for 2008 and 2007 resulted in a reduction of 3,415 metric tons of CO_2 emissions. This is the equivalent of the annual greenhouse gas emissions resulting from 640 passenger vehicles, or the consumption of 396,413 gallons of gasoline, or the electricity used by 484 homes. A graph of the cumulative CO_2 savings (i.e. higher numbers are better) is provided in Figure 5.

IMPACT ON THE INDOOR ENVIRONMENT

As impressive as the energy savings are, the primary function of the building is to provide a safe, comfortable, and healthy place for Boeing employees to work. Programs that reduce energy use by keeping indoor temperatures too warm in the summer and too cold in the winter do not meet this requirement, and ultimately they make employees uncomfortable, unhappy, and unproductive. Similarly, programs that don't properly control humidity levels or that reduce ventilation below acceptable levels not only make employees unhappy, they can cause health problems. By installing the previously described environmental index in the Bay Area Building, Boeing was able to monitor the indoor

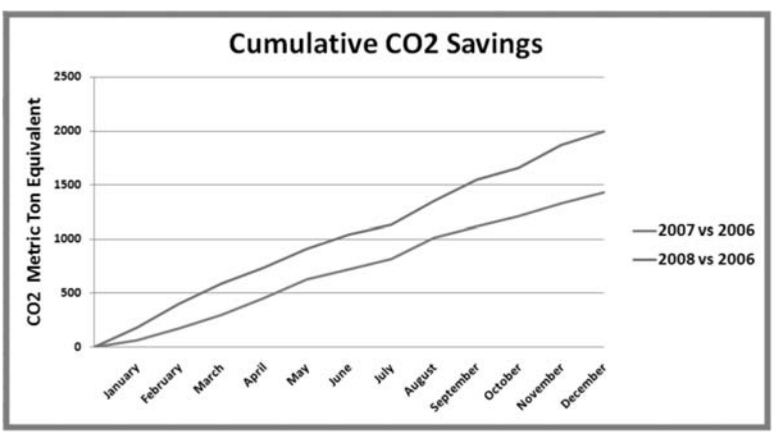

Figure 5. Cumulative CO_2 Savings

environment and ensure that their energy program did not adversely affect their employees. Since the environmental index was monitored by the DDC control system, they did not have a 2006 baseline to show the improvements in comfort that resulted from the revised controls, but they were able to demonstrate that the environmental index remained high, and actually improved, as new energy saving initiatives were brought on-line (Figure 6).

Figure 6 shows that the environmental index was in the high 90's on a 100 point scale for almost all of 2007 and 2008. This indicates that conditions inside the building were very comfortable. Conditions actually improved slightly in 2008, showing that efficiency and comfort are not mutually exclusive. Often the more efficiently a piece of HVAC equipment is running, the better it maintains conditions in the building. (The indices for November and December 2008 were slightly below the figures for 2007, but not because conditions deteriorated in 2008; the indices for 2007 were extraordinarily high.)

CONCLUSION

The energy savings at the Boeing Bay Area Boulevard building show that a committed owner who focuses on high payback initiatives can achieve significant energy reductions in an existing building. The results are especially impressive, because the only major retrofits were

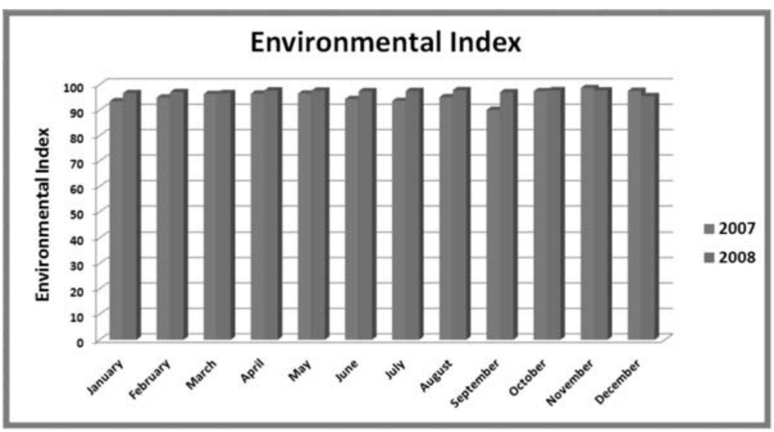

Figure 6. Environmental Index

the installation of a DDC control system with lighting control, replacement of the original outside air-handlers and exhaust fans with ERUs, and the replacement of a single chiller. Most of the energy initiatives involve refining control sequences for the existing mechanical equipment and repairing or recommissioning existing systems as necessary. With these changes, Boeing reduced their energy use by over 27 percent in two years. Equally important, they did it while providing a healthy, comfortable work environment for their employees. Boeing entered their building into the EPA's Energy Star program and became an Energy Star listed building in 2008 [2], having brought their Energy Star rating up from 42 in 2006 to 76 in 2008.

References

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2. Energy Star Labeled Building Profile, Boeing Bay Area Boulevard, web site: http://www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showProfile&profile_id=1006332, US Environmental Protection Agency.

ABOUT THE AUTHOR

Steve Tom, PE, PhD, is the director of Technical Information at Automated Logic Corporation, Kennesaw, Georgia, and has more than 30 years experience working with HVAC systems. At ALC, Steve has coordinated the training, documentation, and technical support programs, and he frequently works with the R&D engineers on product requirements and usability. Currently Steve is directing the development of www.CtrlSpecBuilder.com, a free web-based tool for preparing HVAC control system specifications. He also helped develop EquipmentBuilder, an automated engineering tool for creating control logic, which is built into ALC's Eikon LogicBuilder programming tool.

Prior to joining Automated Logic, Steve was an officer in the U.S. Air Force, where he worked on the design, construction, and operation of facilities (including HVAC systems) around the world. He also taught graduate-level courses in HVAC design and controls at the Air Force Institute of Technology. Mr. Tom can be contacted at stom@automatedlogic.com.