Innovative, Cost Effective and Energy Efficient Design for New Construction at a Texas High School

Saleem Khan, P.E., CxA
Principal

Mitch Bible, CEM
Project Engineer

Texas Energy Engineering Services, Inc.
1301 Capital of Texas Highway, B325
Austin, Texas 78746, USA

ABSTRACT

Energy conservation measures such as high efficiency equipment retrofits, controls upgrades, and commissioning have become popular ways to reduce existing buildings' operating costs. However, cost effective efficiency measures applied to new construction in the design phase can result in greater operating efficiency and environmental impact. These measures entail innovative design concepts and control schemes in addition to specification of premium efficiency equipment. This paper presents Mechanical, Electrical and Plumbing (MEP) design, with primary focus on the HVAC and Controls aspects for Laredo Independent School District's (LISD) Nixon High School in Texas. Energy and water conservation was considered in nearly every aspect of the design, which includes innovative dual-duct Variable Air Volume (VAV) systems for cooling and pre-treated ventilation air delivery integrated with occupancy sensors and digital controls, and optimized HVAC controls for dynamic balancing of air and hydronic sides. The project demonstrates how investment during the planning and design phase can potentially pay dividends by substantially reducing facility lifecycle costs.

INTRODUCTION

As energy prices continue to rise in today's economy, utility costs are becoming an increasingly critical part of institutional budgets. As such, energy efficiency in institutional buildings and minimizing lifecycle costs has become a major consideration. In addition to reducing direct costs, efficiency projects can also have the added benefit of raising public awareness of sustainability, reducing carbon footprint, and mitigating strain on the power grid through peak demand reduction. For existing buildings, many project options exist to yield energy savings with the potential to pay off the project capital cost over time. Replacing equipment such as HVAC units with premium efficiency units or upgrading to digital controls can result in significant cost & energy consumption savings, ranging from moderate to high return on investment. However, such projects are still limited by the existing system type (i.e. single zone, multi-zone, etc.) and infrastructure (ductwork layout, chilled water vs. direct expansion, etc.), which can preclude optimized savings. Lighting replacements typically have shorter paybacks which make them attractive projects. However, peak efficiency options such as LED lighting, which also come with lamp-life/maintenance benefits, have higher upfront costs. Finally, programs such as commissioning and HVAC control sequence optimization can yield some of the best savings and paybacks of any project for existing buildings. But they are also inherently limited due to working within the existing systems performance limits, which may be sub-optimal to begin with.

Energy efficiency upgrades to existing buildings, following careful economic and engineering analysis, will yield results and are in general good investments. However, many aspects of *new construction design* can make investment in energy efficiency and sustainability during the initial design and construction stages even more attractive. Efficiency measures in new construction have return on investment based on the incremental cost difference between high efficiency equipment and the minimum code-required standard alternatives. This often makes premium options more advantageous for the owner from a payback perspective. Moreover, the "blank canvas" of a new design can be used to better integrate system types, infrastructure, and controls to further optimize energy usage, reduce building lifecycle costs, and improve overall environmental impact.

Recently, cost effective and innovative design techniques focused on sustainability were applied to a design for Nixon High School located in Laredo, Texas. Even with this commitment to improved energy efficient design, the overall first cost of the project was kept within budgeted parameters. Although new construction commissioning is not part of the scope of our services for this project, studies have shown that commissioned buildings can achieve 10 to 20% savings per year compared to non-commissioned buildings.

FACILITY AND SYSTEMS DESCRIPTION

The Mechanical, Electrical, and Plumbing (MEP) design under study is for an approximately 200,000 square foot new construction facility at an existing Nixon High School campus. The two-story addition includes new library, administrative offices, mini server rooms, classrooms, computer labs, visual and performing arts, culinary arts and new athletic facilities. This new addition replaces over forty-five year-old existing structures and will be integrated into existing science labs, classrooms, cafeteria, and competition gymnasium built in the last eight years. Existing structures to be replaced primarily use single zone constant volume split direct expansion (DX) HVAC systems with electric heat and DDC controls acting primarily as digital time clock with zone temperature control option.

The design features were carefully selected to match Laredo’s unique climate, where predominantly cooling is required for most of the year. The new design incorporates various aspects to meet the local expertise, weather conditions, and sensitivity towards first cost. The design is to meet applicable building codes such as the International Building Code (IBC), International Mechanical Code (IMC), International Plumbing Code (IPC), International Energy Conservation Code (IECC), and National Electric Code (NEC).

HVAC

The central plant is designed for multiple high efficiency air cooled chillers (approximately 620 total nominal tons). The chilled water distribution system is designed for efficient constant primary and variable secondary pumping configuration. For locations remote from the central plant, multi-stage DX VAV systems with energy recovery will be utilized. Cooling for multiple small server rooms spread across the campus will be provided by small high efficiency ductless split systems, with back-up source of cooling from central air handling units serving nearby spaces. All air handlers with fan motors over 3 horsepower are specified to be equipped with Variable Frequency Drives (VFDs).

For classroom air distribution, a unique approach was taken by utilizing predominately dual duct systems, with one duct providing for space sensible load needs, and the other delivering pre-treated outside air to meet space ventilation requirements. VAV boxes are to be pressure independent in order to maintain consistent supply flows, particularly on the ventilation side. Single zone units with variable air volume capability will be used for large spaces such as the library, gymnasium, and theater black box. Electric resistance heat with staging option at the air-handlers will satisfy zone heating requirements. All HVAC is to have Direct Digital Control (DDC) through a Building Automation System (BAS) with graphical front end.

Lighting

The high school's lighting system design consists of LED lay-in strip fixtures in the interior, an option that the District selected over standard fluorescent fixtures, and LED area lights at the exterior. Gymnasium and other high bay areas will also use LED fixtures in lieu of the traditional High Intensity Discharge (HID) lighting. Lighting occupancy sensors are also an integral part of the design, along with scheduled relays for zone lighting control through the BAS. All interior lighting is designed with dimming control.

Plumbing

In addition to selecting energy efficient equipment, low flow plumbing fixtures were selected to minimize water consumption. Low gallon-per-flush toilets and low-flow faucets will be used in all new restrooms, while locker and dressing rooms will be equipped with low flow shower heads.

HVAC AIR DISTRIBUTION SYSTEM AND CONTROLS FEATURES

Dual Duct VAV Systems

A unique dual duct system with pressure independent dual duct VAV boxes is designed to help maximize energy and ventilation efficiency and improve responsiveness to actual operating conditions. Traditionally, dual duct boxes are used to separate cold deck and hot deck air for flexible supply air temperatures varying from zone to zone. In this case, the hot deck side of each box is served by a separate dedicated Outside Air-handling Unit (OAHU). The pressure-independent boxes allow for precise control of treated outside air delivery to each zone. The cold deck side of each box is served by air handlers designed to handle space-sensible loads. To reduce first-cost and space constraints above the ceilings, these units were designed for plenum return.

In a traditional VAV or multi-zone system where outside and return air streams are mixed and then passed through the air handler, all zones in the system are dependent on the zone requiring the highest percentage of outside air. As a result, the majority of zones in the system would be over-ventilated, requiring costly cooling and dehumidification of the extra outside air at the unit. On a wet-bulb design day in Laredo, one cubic foot per minute (CFM) of outside air can require nearly twice as much energy to cool to supply conditions than one CFM of return air. Figure 1 illustrates ventilation requirements for a traditional VAV system based on all zones meeting the highest zone percent outside air. Actual ventilation code calculations are slightly more complex though similar in concept (IMC 2009).

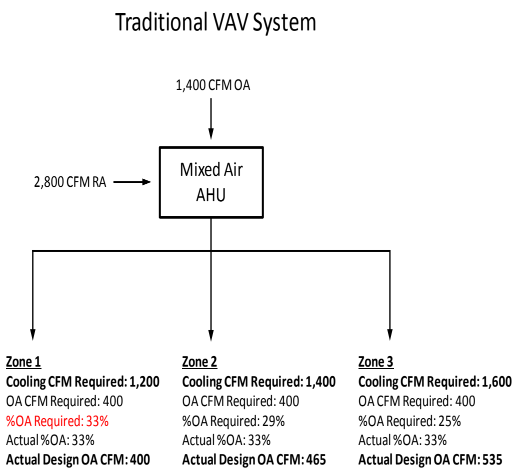

Figure 1. Simplified analysis of ventilation requirements for traditional VAV system based on highest zone percent outside air.

In the dual duct VAV system designed for Nixon High School, all zones can be ventilated precisely to code requirements, as demonstrated in Figure 2. Compared to a traditional system, given the same space cooling loads, the dual duct system requires approximately 15% less outside air at design conditions, which translates to energy and cost savings. In addition, the dual duct VAV design includes classroom occupancy sensors integrated into the BAS VAV box controller, enabling both temperature and ventilation setbacks during periods of sensed vacancy.

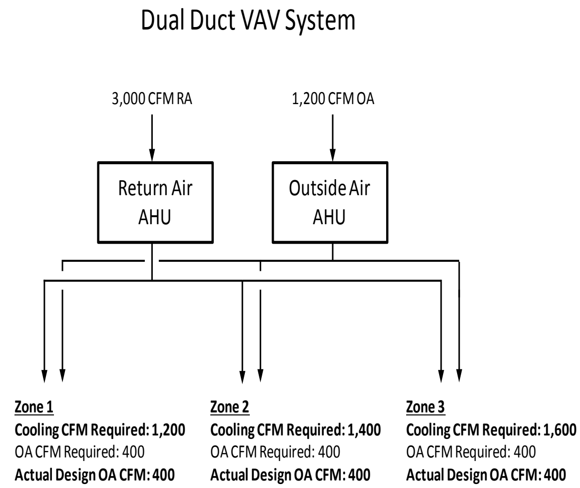

Figure 2. Simplified analysis of ventilation requirements for dual duct with split return and outside air streams.

The ventilation rate required by code is a function of both the area of the space and the occupancy at any given time (IMC 2009). This means that when a space is only partially occupied, full design outside air is not needed. These periods of partial-occupancy can lead to overcooling and occupant discomfort when shell and internal loads are low, but the design volume of treated air outside air is still being supplied.

The design team analysis indicated that differential ventilation code requirements for varying occupancy closely track the cooling CFM requirements according to the standard assumptions as indicated in the upper left box in Figure 3. That is, as people leave or enter the room, the sensible heat that they bring will require additional cooling CFM approximately equal to the additional ventilation CFM per person required by code. Figure 3 below shows the results of this analysis, with the outside air volume required by code for varying occupancy in a typical classroom plotted against the sensible cooling requirement for those occupants at two different levels of space lighting. The would-be steady state temperature for each occupancy condition is also plotted if the supply CFM were constant at the design ventilation requirement, showing potential overcooling.

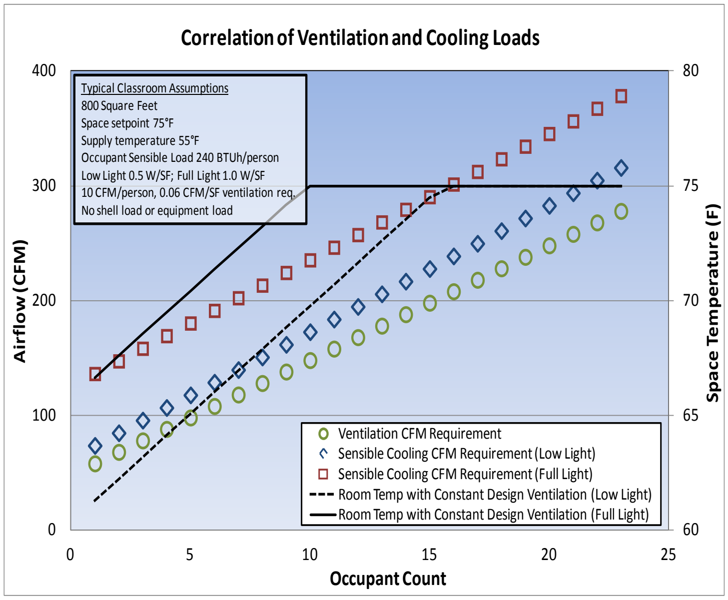

Figure 3. Analysis of ventilation and cooling CFM correlation for a "worst case" over-ventilation/over-cooling scenario in a typical classroom.

These findings resulted in a sequence that treats the air stream providing for space sensible needs, and the air stream delivering pre-treated outside air, as two separate stages of cooling. As the cooling load decreases from design (i.e., the maximum CFM), the space sensible air CFM will be reduced as needed to a minimum of zero (damper fully closed). As cooling load decreases even further, pre-treated outside air CFM will then be reduced from design levels down to a minimum of zero (when motion sensor detects zero occupants). The volume of fresh air needed to cool the space at this point will be at least as much *or more* than is required by ventilation codes, as determined by the previously described preliminary analysis. This system allows for essentially zero minimum flow for each VAV zone without violating ventilation codes, something that is unattainable for most traditional VAV systems, although desirable from an energy usage and comfort standpoint. Figure 4 shows a graphical representation of the control logic for the dual duct systems when the system is in cooling mode.

When outside air temperatures and dew points are favorable, the system may employ an “economizer mode,” during which pretreatment and dehumidification of fresh air is not necessary. Due to the climate in which the school is located, the system will most often employ the cooling sequence described above. However, if heating is required, the system will maintain zone ventilation flows at design levels, while modulating the space sensible air CFM as needed to maintain the zone heating setpoint. A dedicated OAHU has an additional design feature that allows the discharge air temperature to be reset based on demand, while ensuring the required minimum flow for heater operation.

At the air-handlers serving the VAV boxes, sequences are designed for automatic (dynamic) balancing of the system and optimization of energy usage. Air-handlers will poll VAV boxes served and calculate the most open damper position. The downstream static pressure setpoint for the supply fan VFD will be modulated to maintain the most open damper at nearly full open. This will ensure that system airflow is throttled using fan speed, and not system resistances such as zone dampers. As described previously, climatic conditions and previous design experience in the area indicate that zone-by-zone electric reheat is not necessary. Therefore, electric heating will be at the air-handlers only and active when no zones are in cooling, with no individual terminal reheating in the VAV boxes. This feature also helped reduce the initial cost of the system.

Single Zone VAV Systems

Large spaces such as the new library, gymnasium, and theater black box will be served by variable air volume capable single zone units equipped with VFDs. Because more energy can be conserved by reducing cooling via reduced air-flow than by increasing supply temperature, the control sequence was again designed for "two-stage" cooling, with cooler supply temperature being the first stage, and increased fan speed being the second. The control logic for the single zone units is described below.

When the outside air dew point is less than 55° F ("dry" conditions), and minimum levels of cooling are required, the system maintains the fan at minimum speed and modulates the chilled water valve to maintain a discharge air temperature of 65°F. As the cooling requirement increases, the discharge air temperature setpoint is decreased linearly as the thermostat response increases. The chilled water valve continues to modulate to maintain the prevailing discharge air setting. This process constitutes the first stage of cooling. If the discharge air setpoint reaches a minimum of 52°F (adjustable), but additional cooling is required, the system employs a second stage of cooling in which the supply fan speed continually increases as the cooling requirement increases. That is, during the second stage of cooling, the fan speed increases linearly with the thermostat response.

When the outside dew point is greater than or equal to 55° F ("wet" conditions requiring some pretreatment), and cooling is required, the system will follow a similar two-stage process. However, the system will modulate the supply air temperature only between 52°F and 55° F.

When heating is required, the system will follow a similar two-stage process. During the first heating state, the system increases the supply air temperature by increasing the power to the heater, while keeping the fan speed at a minimum. During the second heating stage, when the heater is operating at maximum power, the fan speed continually increases as the heating requirement increases. The minimum fan speed must be sufficient to deliver the manufacturer-recommended CFM across the heating element at all times.

Figure 5 shows the control logic of the sequence for a "non-dehumidification" mode when outside air dew point is less than 55°F. During periods where dew point is over 55°F, the supply air temperature setpoint shall have an upper limit of 55°F.

HYDRONIC DISTRIBUTION SYSTEM AND CONTROLS

The Chilled Water (CHW) system for the school is designed for three air-cooled chillers: two 250-ton, and one 120-ton. The two 250-ton chillers are expected to provide sufficient capacity for peak load conditions. The third chiller was added to provide some redundancy and future expansion capacity, while also serving as a "pony chiller" for lighter load periods to prevent compressor cycling. An air-cooled CHW plant was selected over a water-cooled system due to lower first costs, water conservation considerations, and relative ease of maintenance and upkeep. The chillers will be staged in the BAS based on the percent of Rated Load Amperes (%RLA).

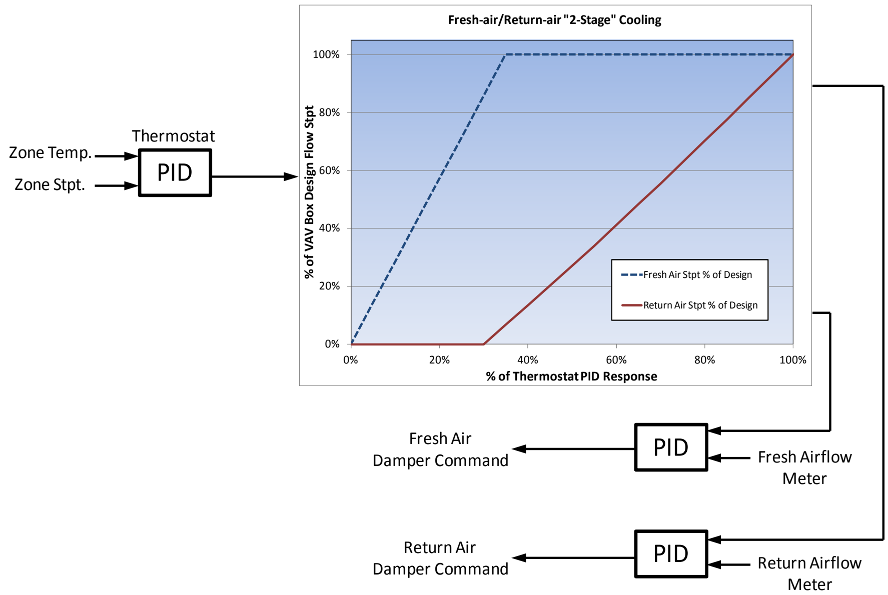

Figure 4. Dual Duct VAV box control logic schematic in occupied mode when motion is sensed in the zone.

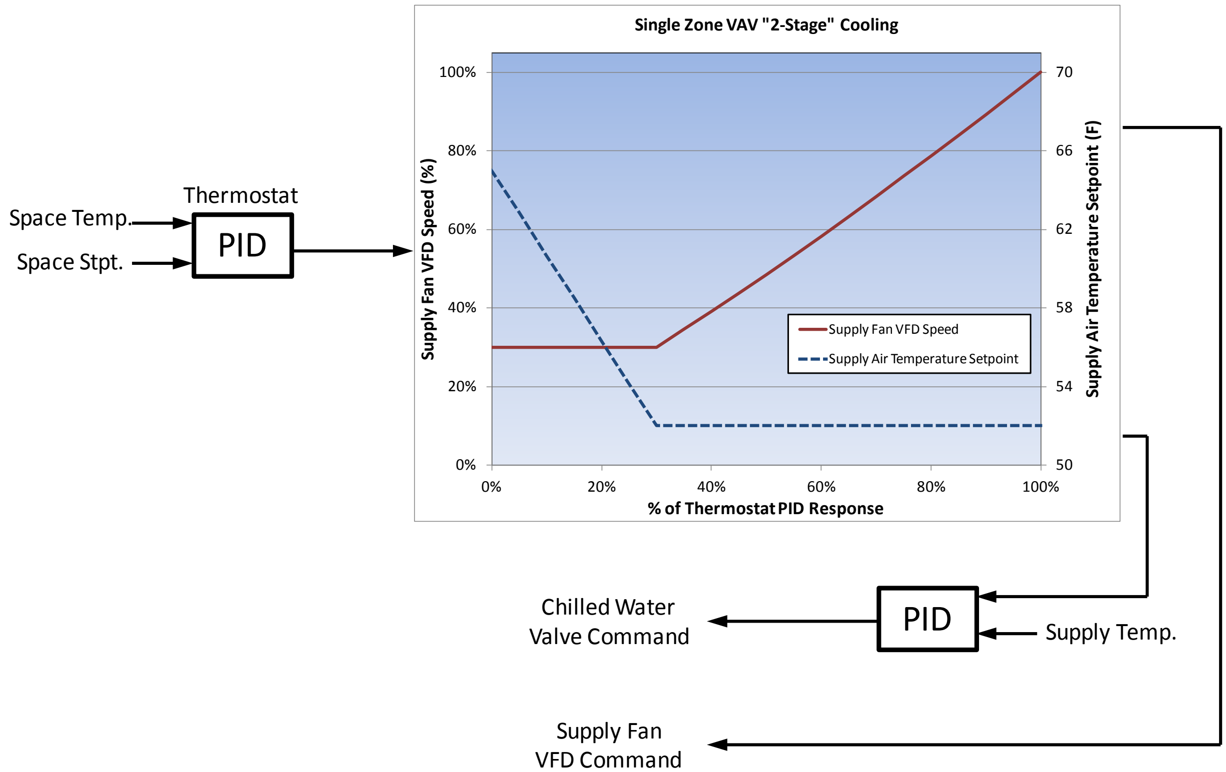

Figure 5. Single Zone VAV air-handler control logic schematic in normal "non-dehumidification" mode.

Constant primary, variable secondary pumping is scheduled to be used at the central plant. Two secondary pumps working in parallel provide distribution throughout the campus loop. The secondary pump VFD speed will be controlled to maintain a differential pressure (DP) setpoint, measured across the building loop piping at the central plant. This pressure setpoint will in turn be modulated to maintain the most open AHU chilled water valve at 95% open. Similar to the strategy for VAV AHU fans, this will ensure that pump head and power are optimized by throttling flow with pump speed, rather than valve resistance. Figure 6 shows data taken from an existing high school where a variable DP strategy was implemented and its results analyzed. It can be seen that this resulted in significant pump speed reduction over the existing constant setpoint control, given similar load conditions (plot normalized for outside air temperature).

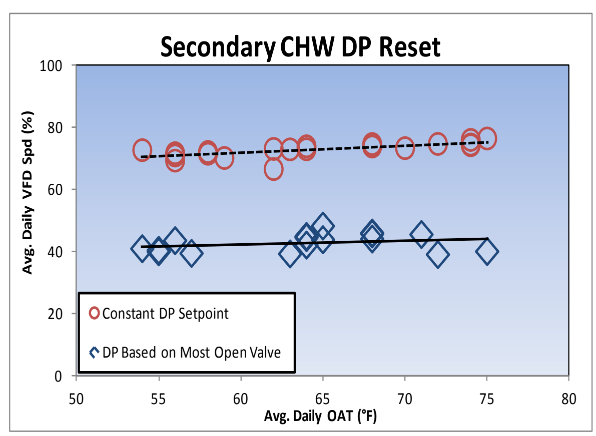

Figure 6. Secondary pump speed reduction from control based on most open air handler chilled water valve.

CONCLUSION

The MEP design for LISD's Nixon High School strongly considered energy efficiency and sustainability, while still accommodating budget constraints and provisions for improved occupant comfort. Energy and water efficient equipment was selected, including high efficiency chillers, LED interior and exterior lighting, and low-flow plumbing fixtures. Air cooled chillers and electric resistance heating were selected to reduce first cost and long term maintenance costs. In order to provide precise and efficient outside air cooling and delivery, an innovative dual duct VAV design was employed with one duct providing for space sensible needs, and the other duct delivering pretreated outside air. Finally, control sequences were customized for the system to continuously track occupancy and cooling loads, both air and water-side, and provide dynamic balancing and, to a certain degree, "self-commissioning." Although not within the scope of the current project, the authors recommend incorporating new construction commissioning consisting of functional performance testing, fine-tuning, and in-depth training of maintenance personnel, in order to ensure that new building design sustainability aspects are fully realized.

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REFERENCES

International Mechanical Code 2009

International Energy Conservation Code 2009

ASHRAE 2010. ANSI/ASHRAE Standard 62.1-2010. *Ventilation for Acceptable Indoor Air Quality (ANSI Approved).* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE 2010. ANSI/ASHRAE Standard 55-2010. *Thermal Environmental Conditions for Human Occupancy (ANSI Approved).* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc