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04.
CURRENT TRENDS IN LOW-ENERGY HVAC DESIGN

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ABSTRACT

The objective of this paper is to provide some insight into how HVAC systems are changing to meet the drive towards lower energy usage. The paper is primarily focusing on trends, observed by the author in designs which have been highlighted in research journals and project work. A case study is provided which highlights how some of the trends have been implemented on a current design.

KEYWORDS: Heating, Ventilation and Air Conditioning (HVAC), Dedicated Outside Air Systems (DOAS), Ventilation decoupling, Variable Air Volume (VAV)

1.0 INTRODUCTION

Throughout the 20th century, trends in HVAC design have been determined largely by technological advances and energy costs. Engineers have always sought to find new ways to ensure occupant comfort, but the level of attention devoted to finding innovative ways to reduce energy use has fluctuated over the last few decades. When energy costs have risen, energy efficiency has become a priority; when they have been low, it has been less of a design driver.

This article identifies several trends which are being used to reduce energy use in commercial buildings. The trends to be considered include decoupling of ventilation and heating/cooling, designing systems for optimal efficiency, increased analysis in system design, and total building integration. This article is not intended to be a technical argument or justification for selection of one system against another. Many technical articles are available for more complete handling of each of the trends.

2.0 DESIGN TRENDS

2.1 Decoupling of Ventilation and Heating/Cooling

The current movement in HVAC design toward the decoupling of ventilation and heating is in some ways a return to the past. Prior to the widespread use of cooling for buildings, perimeter radiation of some form was typically used for heating, with operable windows providing ventilation.

Following World War II, use of air conditioning became more common, mainly driven by prosperity and the manufacturing boom. Early air conditioning systems combined heating, ventilation, and air conditioning into a single system, delivered by the building's central fan and air distribution network. This fan system typically delivered a mixture of outdoor air for ventilation along with warm or cool air to meet the building's temperature requirements. Larger buildings would have separate systems or zones for interior and perimeter spaces. In more extreme climates, a perimeter heating system may also have been installed or reheat coils provided on ducts serving perimeter spaces.

As prices soared during the energy crisis of the 1970s, engineers looked for a way to reduce costs and improve space comfort conditions. One solution, dual duct systems, provided warm air through one duct and cool air through another. The air would then be mixed at the zone level to provide appropriate temperature supply air for the zone's needs, typically at constant volume. Dual duct systems allowed buildings to be divided into many more zones while using a larger central fan system. Dual duct systems also eliminated the need to re-heat air at the zone level resulting in less re-heat energy and reducing the piping network throughout the building.

The next major innovation to emerge included variable air volume (VAV) systems which eliminated the warm air duct and kept airflow from the system at a constant temperature of approximately 55° to 58°F. VAV systems reduced energy consumption by reducing the quantity of air delivered to the space, matching the quantity of air delivered with the cooling needs of the building. Depending on the ratio of interior to perimeter space and the facade loads of the building, a VAV system could reduce the air quantity delivered to the space by 50% or more, which reduced the amount of fan energy consumed. Another benefit inherent to the VAV system was a reduction of the total system capacity since the system is based on a diversified "block" load which compensates for load variations within the space due to occupancy and solar loads.

Current industry trends are moving HVAC design away from VAV systems, which provide both ventilation and heating and cooling, to decoupled systems which either partially or completely separate the ventilation air from the cooling and heating functions. The primary cost savings associated with decoupled systems is the result of a reduction in fan energy. In one common example, a dedicated outside air system (DOAS), the airflow provided by the fan system is limited to the code-required ventilation component. The DOAS air handling unit provides heated and de-humidified air for ventilation and is frequently provided with some form of heat recovery component such as enthalpy transfer wheels, "run around" coils or heat pipes to further reduce energy consumption by utilizing building exhaust air to pre-condition the ventilation air. A DOAS system typically provides 20% or less airflow than what would be provided at peak cooling periods utilizing a VAV system. With a DOAS system, the heating and cooling requirements for the space are met through a water-based system. Since water has a much higher capacity for energy transfer than air, the amount of energy required to deliver the heating and cooling is greatly reduced, while pump energy is somewhat increased. A side benefit of the reduced air quantity is smaller ductwork, which decreases the cost of the ventilation system and, potentially, the building's required floor-to-floor height. DOAS systems are typically paired with passive chilled beams, radiant heating/cooling, or fan coils.

When applying DOAS and chilled beam systems (shown in Figure 1), the designer must be careful to pay attention to how the air is distributed to the space and how heating is accomplished. In buildings with low heating needs, the ventilation air may be able to provide adequate heating. In buildings with higher heating requirements, supplemental heating systems such as perimeter baseboard may be required. It is critical that the ventilation air reach the occupied breathing zone. For this reason, DOAS systems are frequently configured to deliver the air with a displacement strategy at low level.

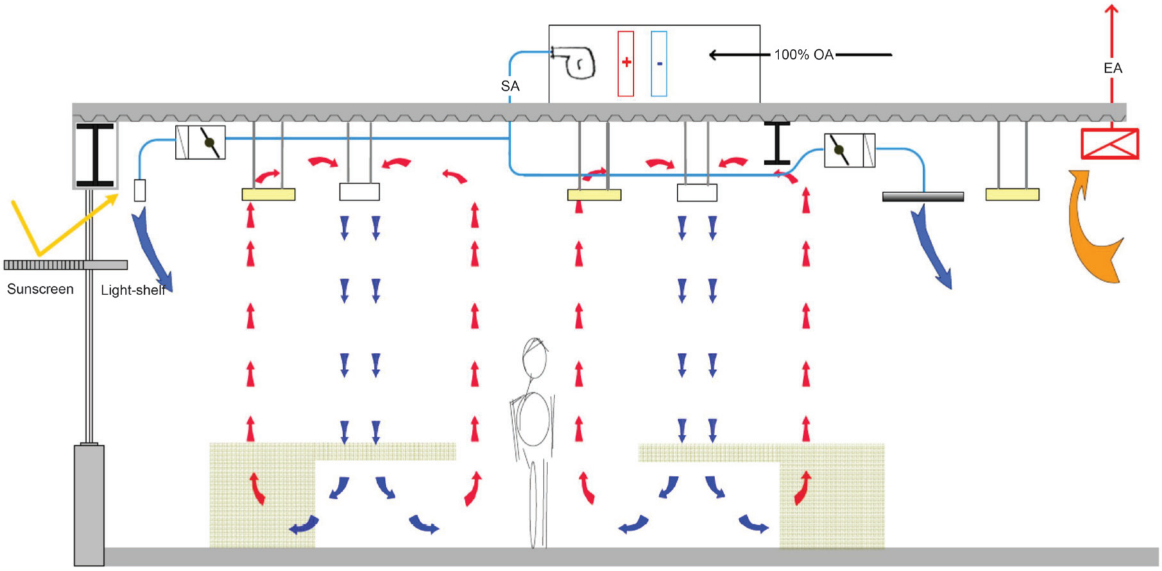

Figure 1: Passive chilled beam system diagram.

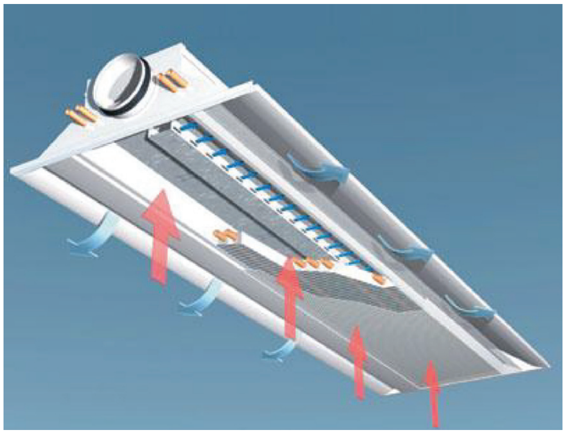

Figure 2: Active chilled beam diagram.

A second type of decoupled system could be considered a hybrid model. Active chilled beams (shown in Figure 2) deliver both ventilation and heating/cooling services, but induced air at the chilled beam delivers most of the heating and cooling while the air handling unit provides only a portion of the requirements. A primary air duct system provides either 100% ventilation air or a mixture of return and ventilation air, depending on the system configuration. The primary airflow for an active chilled beam system is more than that of a DOAS/passive chilled beam system because the active chilled beam utilizes the primary air to induce room air across the coil in the beam. The static pressure in the primary air system may also be higher than that of a DOAS system. Similar to the DOAS/passive chilled beam system, the active chilled beam system delivers pre-heated and dehumidified air to the space through use of an air handling unit which frequently is provided with a means of heat recovery.

We analyzed a simple 20-story building to compare the DOAS/passive chilled beam system and the active chilled beam system to an ASHRAE standard 90.1 baseline VAV system. The results of the study are reflected in Figure 3.

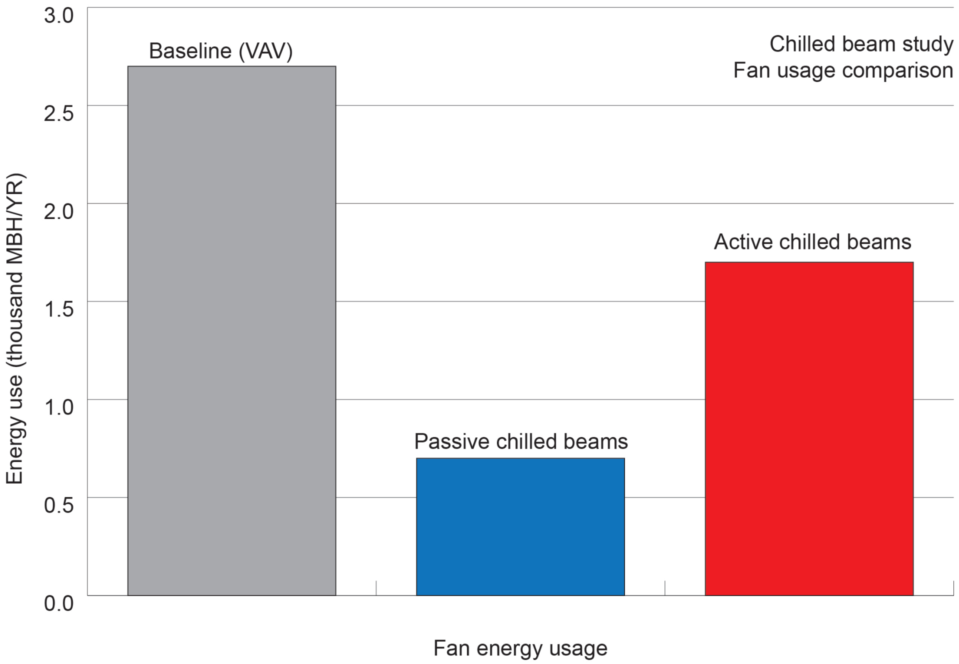

Figure 3: Fan energy comparison.

2.2 System Design for Equipment Efficiency

To take full advantage of new high-efficiency equipment, it is necessary to design the overall system to operate at parameters which correlate to the equipment's best efficiency. While this may seem obvious, too often high-efficiency equipment is specified and applied in systems whose operating parameters do not allow the equipment to realize its best possible efficiency.

One example of this occurs when condensing boilers are applied to systems in which the temperatures are maintained above the point at which condensing occurs, thereby reducing the actual operational efficiency. As seen in Figure 4, boiler efficiency decreases with return water temperature and increased firing rate. While the 87.6% efficiency of the boiler with return water at 160°F exceeds the ASHRAE requirement of 82% for boilers, the equipment is capable of much higher efficiency if the system can be configured for lower return water temperatures. Installing higher capacity equipment which allows for lower operational firing rates also increases efficiency.

System design approaches such as including radiant floor heating, selecting air handling unit coils for lower inlet temperatures and higher differences in temperatures, and arranging heating devices in series can reduce the return water temperature and substantially increase the overall system efficiency. In this manner, it is possible to achieve operational boiler efficiencies in excess of 95%.

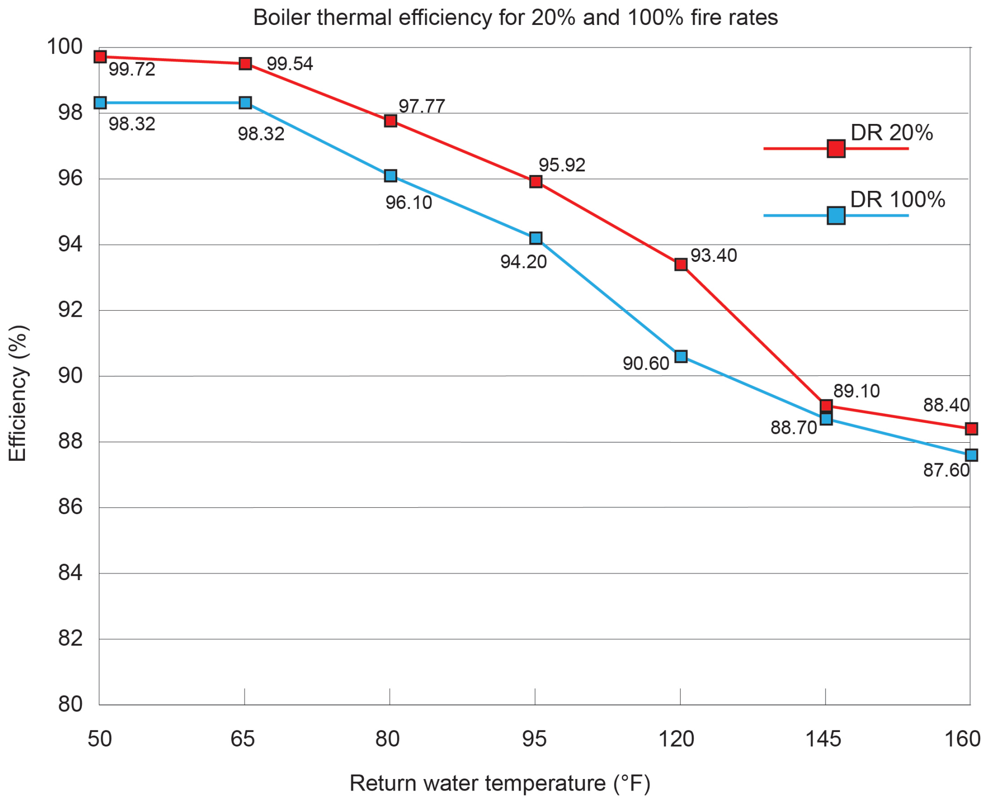

Figure 4: Condensing boiler efficiency diagram (Source: Camus Hydronics).

A similar approach can be applied to the chilled water system. Utilizing systems such as chilled beams allows the designer to use higher chilled water temperatures to provide cooling which allow for equipment selection at improved efficiency.

The use of modular equipment can also improve system efficiency. Selecting and applying equipment such as modular chillers helps each module operate at or near its peak efficiency. The modular chiller can also be more easily applied to allow for variable chilled and condenser water flow through the use of isolation valves and multi-cell cooling towers.

2.3 Design Analysis

Applying new system types and altering design parameters requires the design team to conduct additional analyses to ensure the desired results. Designing for maximum efficiency requires the engineer to go beyond basic load calculations — adequate for ensuring building comfort — and take the next step: modeling hourly system loads to determine overall efficiency and optimize equipment and operational parameters.

Energy modeling programs such as EnergyPlus, Trane Trace, Carrier HAP, and IES provide detailed hourly information about system load requirements which enable the engineer to compare different system types and equipment configurations. In the past, these programs were typically used only with complex, large-scale buildings or projects seeking LEED certification. Today, however, more projects are being analyzed and optimized.

Another analysis method which is becoming increasingly used is computational fluid dynamics (CFD) analysis. CFD modeling uses differential equations to predict temperature and airflow patterns throughout a space, allowing the engineer to study alternative approaches to system design without relying as extensively on past experience or conventions. For instance, Arup used CFD analysis at the University of Chicago's Early Childhood Center to verify that radiant floor heating could be applied adjacent to a tall glass wall without leading to significant downdrafts, which could cause occupant discomfort. Diagrams shown in Figures 5 and 6 indicate the temperature and velocity contours. Without the CFD analysis, a more conventional system with baseboard heat or radiant ceiling panels would have been used for the project. In addition to providing a warm floor for comfort, the radiant floor system enabled the use of lower heating water temperatures, increasing system efficiency by lowering return water temperature and improving boiler efficiency.

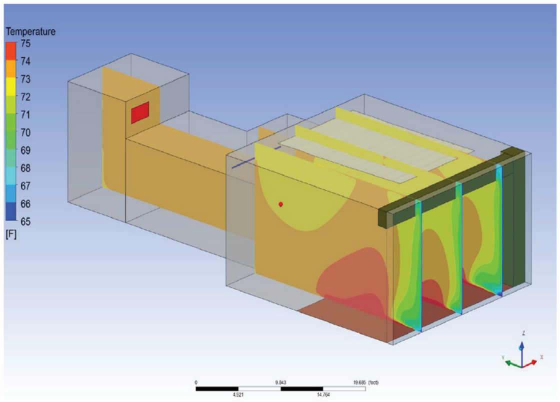

Figure 5: CFD temperature plot.

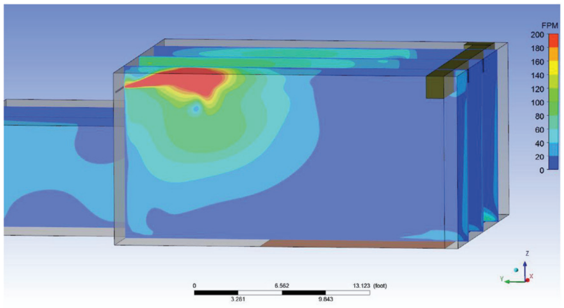

Figure 6: CFD air velocity plot.

2.4 Total System Integration

Another current trend is total system integration, or smart building technology. To maximize energy efficiency in high-performance buildings, everything must work together. Lights, shades, usage scheduling, ventilation, video displays, even desktop telephones — performance of these systems must be integrated, constantly monitored and adjusted in order to maximize energy efficiency.

Linking formerly discrete building elements through wiring and software allows systems to work together. This can reduce not only the energy required to operate a building, but also the overall amount of space required in the building. As an example, a scheduling system that links to conference room occupancy sensors can recognize that a scheduled meeting has been cancelled if occupants are not present within a given time. The scheduling system can then identify the room as available for another meeting. In large conference centers, this has the potential to reduce the total number of rooms required.

Realizing the design of a smart building is a process which requires the integration of the entire design and construction team and close collaboration.

3.0 CASE STUDY: UNIVERSITY OF CHICAGO, LABORATORY SCHOOL – EARLY CHILDHOOD CENTER

Earl Shapiro Hall at the Early Childhood Campus (ECC) is a new 125,000 ft^2 early education center associated with the University of Chicago in Chicago, IL (Figure 7). The building is targeting LEED Gold certification and consists of classrooms, offices, library, and a gymnasium as well as outdoor play space adjacent to the building and on the roof.

The building is expected to achieve a 32% energy cost savings and 39% energy savings over ASHRAE 90.1-2004 baseline (Figure 8). The annual energy savings are primarily obtained through reductions in energy used for heating, cooling, and lighting.

Energy conservation strategies include:

- Low temperature condensing boilers/radiant floor heating
- Modular chillers
- Demand controlled ventilation
- High-performance glazing/curtain wall.

CFD modeling was performed to verify if the design approach utilizing radiant floor heating would result in acceptable temperature and airflow conditions in the finished space (Figures 9 and 10).

Figure 7: Earl Shapiro Early Childhood Campus[1] at the University of Chicago (Courtesy of VDTA/FGM/Visualized Concepts).

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[1] Client: University of Chicago Laboratory School
Design Architect: Valerio Dewalt Train Assoc.
Architect of Record: FGM Architects
Engineer: Arup

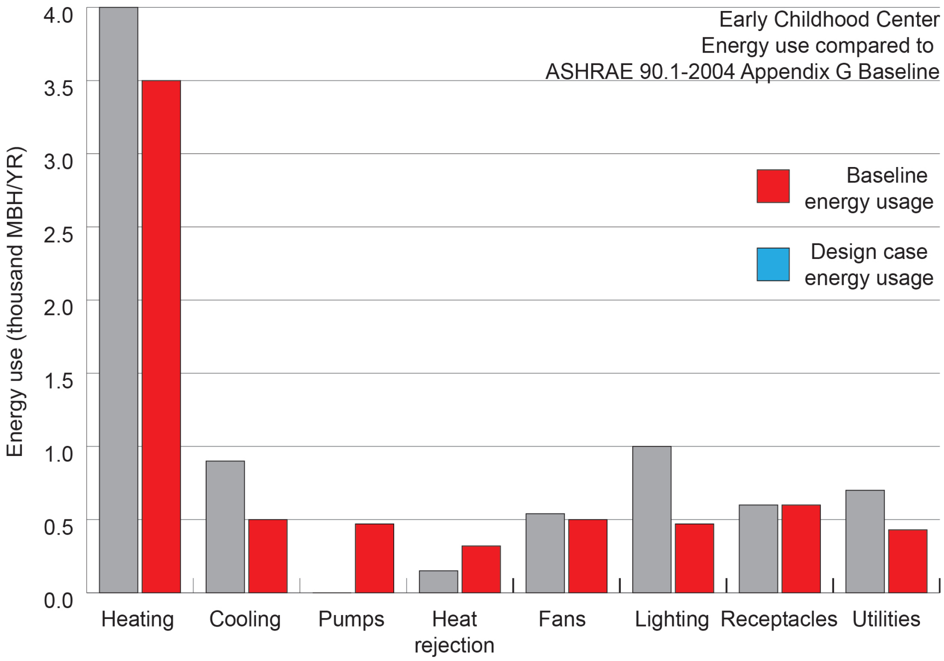

Figure 8: Comparison of modeled energy usage against the ASHRAE 90.1-2004 baseline.

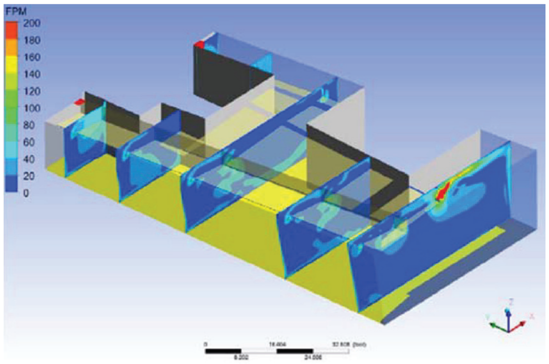

Figure 9: Velocity contours.

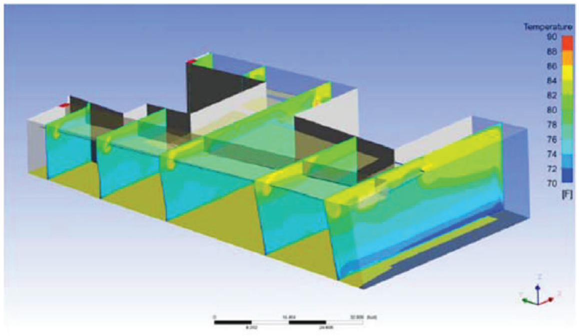

Figure 10: Temperature contours.

4.0 CONCLUSION AND LOOKING TO THE FUTURE

Like all efforts to reduce building system energy consumption, designing a high-performance, smart building requires close cooperation between a number of parties: engineers, architects, contractors, equipment manufacturers, and end users. Due to the highly integrated nature of the process, it is important that all parties share a common vision for the project.

From an HVAC perspective, one of the many unfortunate effects of the recent economic recession has been, counter-intuitively, a relative drop in energy costs in North America. Because consumers and businesses have had less cash on hand for discretionary products and services, energy use has fallen. Because of the way the energy economy is structured, this drop in usage has had the result of keeping prices relatively affordable. While this is obviously beneficial for consumers in the short term, because it has deferred conversations about energy efficiency in the built environment, it has the potential to be damaging to both the environment and the bottom line in the long term. It is therefore even more important for designers to play a key role in educating the public — and one another — about energy efficiency.