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THE ADVANTAGE CLASSROOM ; SUSTAINABLE DESIGN FOR ACHIEVING INDOOR AIR QUALITY, COMFORT, AND AN IMPROVED LEARNING ENVIRONMENT

BY: Loren M. Belida, AIA[2], William A. Turner M.S., P.E.[1], Steven M. Martel, P.E[1]
William Johnson, CFM[2]

[1]The H.L. Turner Group Inc.
Indoor Air Services Division
RR#1, Box 535B
Harrison, ME 04040, USA

[2]The H.L. Turner Group Inc.
Architectural Division
6 Loudon Road
Concord, NH 03301,USA

ABSTRACT

In March of 1996, a new Elementary School was occupied which is the first in the United States to utilize the concept of displacement ventilation as the primary means of providing both good indoor air quality and thermal comfort. In addition, the integrated "sustainable" design concepts of the facility also address other important factors including: siting, programming, lighting, acoustics, energy efficiency, classroom computer usage, and access for planned HVAC preventive maintenance. Ventilation and thermal comfort objectives are achieved through the use of a combination of 100% outdoor air delivered low in the classroom, and the use of demand controlled ventilation. This paper presents a brief explanation of the basic advantages of non-mixing, ventilation systems and discusses the HVAC costs, operational savings, and environmental benefits of implementing this concept. Because of the success of the design in this initial facility, we have pursued this design strategy in several more schools that are currently under construction and are now utilizing this approach for all school designs.

INTRODUCTION

It is generally considered common knowledge, (as recently confirmed by a US Government Accounting Office (GAO) report (1), that a significant percentage of US schools suffer from inadequate ventilation, temperature control, lighting, and generally poor indoor air quality. It is also believed, that in most cases, these poor environmental conditions detract from the learning environment. Based on the success of two years' of occupancy in a displacement ventilation office facility, and review of several publications, (2, 3, 4) the authors hypothesized that for certain applications, i.e. high density classrooms, a properly designed vertical displacement ventilation system should offer many advantages, few drawbacks, and enhance both the learning environment and the "sustainability" of a school facility (5) .

METHODS: Key Differences and Advantages, Displacement Ventilation Design Vs. Conventional Mixing Ventilation

In 1994, because of the openness of a public school system client to try something "new", the authors were provided with an opportunity to further evaluate the feasibility of utilizing "Vertical Displacement Ventilation" as the primary means for providing ventilation and conditioning the space in school classrooms. As designed by the authors for public school classrooms, the vertical displacement ventilation concept is extremely different from conventional ventilation in several important ways. These differences offer many potential benefits over most conventional HVAC systems that are typically found in public or private schools. Key differences and expected benefits include:

- No Drafts: Air is supplied low in the space at extremely low velocity. There is a very low exit velocity and thus no "throw" and little risk of "drafts".
- Stratified Room Air: Supply air is purposely not uniformly mixed throughout the space. It is intentionally stratified vertically to provide a better quality of air in the occupied (approximately lower than six feet) part of the room. The air at the ceiling return or exhaust will typically be 6-12°F warmer than air at the floor when occupied with normal classroom populations and loads. Supply air is delivered during most occupancy at temperatures just slightly lower than desired room temperature, typically at 60 to 65°F. Once this is accomplished, because of density differences, the supply air moves horizontally across the floor slightly pushed by the air behind it coming out of the diffusers. The air naturally rises from the floor driven by convective currents when it starts to warm up due to internal heat from people, lights, computers, etc. The air distribution process takes considerable advantage of the natural thermal convection currents created in a room to distribute supply air throughout the entire space at very low velocities.
- No Recirculated Stale Air: In this design, all supplied air is "preconditioned" 100 % outdoor air and all air removed from the classroom is exhausted outdoors -- none is recirculated. Only the sensible and latent energy is captured from the exhaust air and recycled when needed.
- Room VAV Not Needed: When there are few or no internal loads, such as an unoccupied room with the lights off and little solar gain, the room air will be very slowly displaced upward by the air beneath it, as it moves towards the negative pressure at the exhaust grilles. In this case, the exhausted air will be roughly the same temperature as the supplied air. However, even in this worst case, the resultant room temperature will not fall below the supply air temperature, thus the need for a VAV system to prevent overcooling is virtually eliminated.
- Improved Effective Ventilation: The thermal stratification of the room air can provide significantly better air quality in the occupied zone with less overall dilution air needed for the majority of internal sources, because internally generated pollutants are not uniformly mixed into all of the air contained within the room. Because of body heat, convective currents and warm human breath, there is a rise of exhaled breath above the occupied zone, if it is not greatly disturbed by fan forced air streams (as happens in conventional mixing distribution systems). This means that occupants will breath air closer to supply air conditions (in this case conditioned outdoor air), versus the condition of the air that is being exhausted from the space at the ceiling level, improving the ventilation efficiency. The measurement of these differences is covered in a separate publication (6).
- Reduced Cooling Capacity Needed: Thermal stratification also allows some reduction of internal cooling requirements, because about 50% of the heat from the lights and other sources located above the occupants does not reach the occupied zone and, in this design, is exhausted outdoors when not needed.
- Enhanced Heat Recovery Potential: Vertical displacement is also more conducive to heat recovery during the heating season because the exhaust air will typically be warmer than room air by several degrees.
- Less Fan Horsepower Needed: In this design, supply air flows needed to achieve temperature control and provide ventilation are approximately 50% of conventional

system flows; thus, much less fan horsepower than conventional mixing type systems is needed. In order to achieve low supply air velocities, typically less than 50 ft. per min. (0. 25m/sec), displacement diffusers are large when compared to conventional mixing type diffusers. Low velocity supply of air cannot be accomplished using conventional mixing type diffusers on conventional horizontal unit ventilators or non-ducted fan coils.

- Less Room Noise: With reduced total air flow quantities and low exit velocities there is less noise compared to mixing type systems, because there is no need to forcefully mix air in the room, and less total air flow is needed.
- Less Inter-zone Pollutant Transport: The supply air quality is also improved because it is not mixed with contaminated air within the room as it enters and, with no recirculation, the supply air does not contain contaminants from other rooms or zones of the building.

Conventional Mixing Type Air Distribution Systems: The design parameters for the displacement system are quite different from conventional systems where diffusers are intentionally designed to stir the incoming 55 deg. F. supply air and mix it thoroughly, resulting in uniform temperatures, and uniform pollutant concentrations. To accomplish cooling with less draft, conventional diffusers must have a relatively high discharge velocity, and must be mounted where people will not directly feel the resulting high velocity air flow (usually in or near the ceiling). Non-ducted unit ventilators (UV's) that are traditionally used in a large percentage of public school classrooms cannot provide highly effective air distribution. Their air flow pattern frequently causes occupant perceived drafts, especially when cooling is needed in high density classroom space. It is the experience of the authors that drafts and noise are the most frequently cited reasons why occupants shut off their unit ventilators in schools. In a recent report by a researcher, it was determined that 15 out of 47 properly operating UV's had been shut off by the teachers because of unacceptable noise and draft problems, despite a policy that they be kept on. (7)

RESULTS AND DISCUSSION

Based on the successful measured thermal results of 80% scale mock up testing, and favorable comfort level reporting from the occupants within the mock up when it was occupied, the displacement design approach was integrated for the first time in the design of the Boscawen Elementary School located in Boscawen, New Hampshire. The 48,000 sq.ft, (4,460 sq.meter) school was occupied with 400 students and staff in mid March 1996. A unique ceiling/roof structure that provides a 14 foot feet (4.3 meters) high vaulted ceiling was incorporated into the classroom design to enhance both the classroom space use and to provide room volume above the "shift zone" created by the displacement distribution system. This vaulted ceiling arrangement allows the displacement ventilation concept to work most effectively. The table below presents a summary of the HVAC features incorporated into the school design, including costs and benefits, and the expected reduction of greenhouse gas generation by each feature.

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TABLE #1 ESTIMATED EXPECTED BENEFITS OF HVAC FEATURES

HVAC SUSTAINABLE FEATURE and Cost	SIMPLE PAYBACK OF INVESTMENT	ANNUAL FUEL SAVINGS	ANNUAL COST SAVINGS	ANNUAL CO_2 REDUCTION
# 1 Tightened building shell, 0.08 Vs 0.24Ach $ 8,000.00	S. pay: 4.4 yr. S .pay 3.1 yr.	oil 2,272 gal ng 3,181 therm	$ 1,818.00 $ 2,545.00	= 30 tons = 19 tons
# 2 Latent Heat recovery 70 % eff. $ 29,000.00	S. pay: 10.4 yr. **See Note #1** S. pay: 7.1 yr.	oil 4,002 gal ng 5,602 therm	$ 2,797.00 $ 4,077.00	= 53 tons = 34 tons
# 3 Variable frequency drive HVAC motors, ventilation savings $ 6,000.00	S. pay: 5.2 yr. S. pay 3.7 yr.	oil 1,429 gal ng 2,001 therm	$ 1,143.00 $ 1,601.00	= 19 tons = 12 tons
# 4 Variable Freq. Motors Electric savings $ 15,000.00	S. pay: 4.0 yr.	46,338 kWh oil ng	$ 3,707.00	= 47 tons = 31 tons
#5 Displacement Dehum. vs mix. AC $ -18,000.00 savings	S. pay: yr. **See Note #2**	kWh TBD oil ng	$ TBD	= TBD tons = tons
#6 two switch, high efficiency lighting $ 2,500.00	S. pay: 0.5 yr.	64,800 kWh oil ng	$ 5,184.00	= 65 tons = 43 tons
total investment $ 42,500.00	------------------	----------------	annual total savings $ 17,114.00 **See note #3**	

Notes:

1. Simple payback of 10.4 years for fuel oil would be dramatically reduced if summer operation of school, or if school is located in a southern climate. All simple paybacks would be less than five (5) years if school is located in a climate where cooling is needed.
2. Annual savings for cooling costs not yet calculated as of this writing.(4/30/97)
3. Annual total savings does not include savings for item #5 cooling , as cooling savings have not been calculated as of this writing. (4/30/97).
4. Benefits of good acoustics, lighting, and comfortable, clean, filtered air not calculated.

Assumptions within calculations:

5. Building Size; 4,180 m^2 , (45,000 ft^2) Volume 19,111 m^3 , (675,000 ft^3), Population 400
6. Vent rate 7.08 lps/person, (15 cfm), Climate; Degree days 7,500 deg. F., Occupancy 12 hours five days per week, for 200 days per year (on summer operation),
7. Energy Costs: Oil = $0.80 per gal., Nat.gas= $0.80 per therm, Electricity= $0.08 per kWh
8. CO_2 from oil= 26.4 lb/gal, CO_2 from gas= 12.1lb/therm, CO_2 from electricity 1.54 lb/kWh.
9. Performance of all items would be better if school occupied for more hours each day, or during the summer period.

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Discussion of Table #1 Data: Review of the data presented in Table #1 reveals that all of the listed technical items utilized to enhance the comfort and sustainability of the school offer attractive simple payback periods for a publicly funded facility. The economics of these features would be enhanced further if summer operation were included. If the same basic facility was located in a predominantly cooling climate, it is highly likely that the economics would be even more attractive.

Monitoring Data For Temperature Relative Humidity and Carbon Dioxide: Preliminary collection of basic indicators of thermal comfort and ventilation: (Carbon Dioxide, Relative Humidity, and Temperature) has been undertaken in the first new facility and in one retrofit facility with a low ceiling. The data is displayed in a separate publication (6). Observations of the data reveal achievement of design goals for both thermal control and ventilation air delivery. Additionally, observed extremely rapid equilibrium level of Carbon Dioxide upon occupant arrival, and rapid flushing of the room as the students leave is observed, confirming the achievement of displacement air movement with, and a negligable effect from infiltration leakage. Observations of the data reveal generally acceptable measured temperatures in accordance with ASHRAE comfort criteria.

Expected Lower Maintenance Costs And Higher Reliability With Central HVAC Systems: As indoor air quality consultants. We attempt, when at all feasible, to utilize such design features as centralizing "IAQ package" air handling equipment, and placement of HVAC equipment in easily serviced locations outside of occupied spaces, but within the thermal envelope of the facility. The above features were incorporated into the design of the Boscawen school. We also provided individual annual maintenance checklists posted on each Air Handler. Inadequate preventive maintenance issues have frequently been observed to be a problem with dispersed air handling systems such as unit ventilators, fan coil air conditioners, and water source heat pumps. This has been observed to be especially the case when the equipment is located in ceiling plenums above occupied spaces, where it is hard to access. With centralized systems, the location of air intakes can be carefully selected. With unit ventilators, air is most frequently drawn near the ground where the ventilator is installed. This frequently results in the intake of vehicle exhaust fumes, plant and insect materials, and soil type odors. Historically, unusual odors from outside the classroom have been reported to be a problem in schools. Centralized systems also allow for very good particle air filtration, which is not possible with unit ventilators.

The displacement HVAC system and other associated design features installed in the Boscawen School and two others since, has in general, performed as designed, and the occupants report extreme satisfaction with the resultant indoor environment. Decreasing the likelihood of Indoor Air Quality problems, and enhancing the learning environment in any facility, must begin with sound, conceptual building system designs, and include a cost effective easy to maintain HVAC system. With detailed design and construction work, we are confident that a good quality, low maintenance, central "IAQ package" ventilation system can be installed in most schools within a reasonable budget. Incorporating displacement ventilation into this school design, and all of the other features, has resulted in a design that appears to be highly functional as wells as cost effective. The specific cost exclusive of site costs to construct the new Boscawen Elementary School was \$65. per ft^2. (SI \$701. m^2.); HVAC and plumbing systems making up \$11. per ft^2.(SI \$118.m^2) of the total construction budget.

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