Dual Fan, Dual Duct goes to school

By David Warden, P.Eng., Member ASHRAE

The dual fan dual duct (DFDD) system at Topham Elementary School uses half as much heat per unit area as any other system in the Langley, BC, Canada, school district. Additionally, records show the system has fewer problems and costs less to maintain. Suitable for any climate, this inexpensive form of DFDD offers significant benefits not just for schools, but for most buildings where a central system can recirculate air to multiple spaces.

HVAC System Description

Topham's HVAC design was developed at a time when construction budgets had been cut by 30%. Rather than reduce system quality, it was decided to use DFDD as experience in several building types showed that recent refinements had made it less expensive than traditional systems. It was also hoped to greatly reduce heating costs and equal or surpass traditional systems in all other respects.

A single DFDD system serves the 3,000 m^2 (32,300 ft^2) school. Mechanical cooling is not provided, as per government policy, but can be added easily.

A cold air-handling unit (AHU) mixes cool outdoor air and recirculated air to supply 15°C (59°F) air. When the outdoor temperature is above 14°C (57°F), it supplies 100% outdoor air.

A hot AHU supplies 100% recirculated air. Below 15°C (59°F) outdoor temperature, this air is progressively heated on a schedule rising to 38°C (100°F) at –10°C (14°F). Above 15°C (59°F), it is unheated. Above 22°C (72°F), it switches to 100% outdoor air via the cold AHU.

The hot and cold AHUs each are sized at 70% of total supply including future needs.

High turndown (15:1) furnaces in the hot AHU provide all heat for the building. Furnaces and hot fans are duplexed for heating security.

Most spaces are separate zones with temperature and airflow individually controlled by mixing "hot" and "cold" air. Zone supply flow usually is constant but can be increased (see Classroom Ventilation section).

Outside normal hours, the system can be started from a button on most zone sensors. The system runs for two hours, supplying air to the activating zone, and enough other zones to draw 25% of normal system supply. Coupled with the

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system's inherent efficiency (see Energy section), this provides a flexible, energy-efficient response during partial occupancy, such as use of the gym at night.

Return air passes through the ceiling space. Full-height internal walls have openings above the ceiling, sized for low pressure drop. Relief air is unpowered, and flows through large backdraft dampers.

Each building entrance has a small fan to remove cold air from low level and blow it into the ceiling space. In cold weather, relief dampers that do not face in the same direction as the main entrance are held closed.

Plant Room. The central mechanical plant is sized for future expansion and is located in one plant room sized at 2% of the gross floor area (*Figure 2*).

The plant room is in the building core to save valuable perimeter space and minimize service runs. Roof-mounted equipment is not used except for a small condensing unit for computer room air conditioning.

All scheduled maintenance is in the mechanical room.

Furnaces. As DFDD systems can apply heat centrally and do not need a high-temperature source, they can use almost any source of heat including hot water, glycol, steam, electricity, heat pumps or suitable furnaces. Furnaces were selected for the following reasons:

• Gas was the least costly fuel (heat pump was not considered due to capital cost limits);

• Furnaces cost far less than boilers, pumps and piping;

• No space is required for a boiler plant;

• Indirect-fired gas furnaces were available with 15:1 turndown, more than 80% efficiency at all firing rates, full 10-year warranty, and record of reliable performance exceeding 15 years in other buildings;

• Energy use is less than with any boiler system as heat loss from pipes and boiler casings are eliminated and stack loss is less;

• Maintenance requirements are minimal and much less than for boiler plant; and

• No coils means no risk of coil freezeup.

Most other systems cannot use furnaces as a sole heat source because the systems function by heating air separately at many points throughout the building.

Mixing Boxes. Topham has special shop-fabricated boxes (*Figure 3*) with fuzzy logic control sequences based on discharge temperature and flow. These offer the following advantages over traditional boxes:

• Better control, as sensing flow in a straight high velocity discharge provides a strong, stable signal under all operating conditions. (Traditional inlet flow control breaks down when the hot or cold inlet velocity drops below the sensor's range);

• An easily cleaned probe can replace the cross-flow sensor;

• Less pressure drop (velocity and direction changes are more gradual, and the discharge is designed for static regain);

• Easier installation and replacement (lighter, smaller pieces);

• Less casing-radiated noise (curved box surfaces, not flat);

• Less costly (lower box cost and one flow sensor, not two);

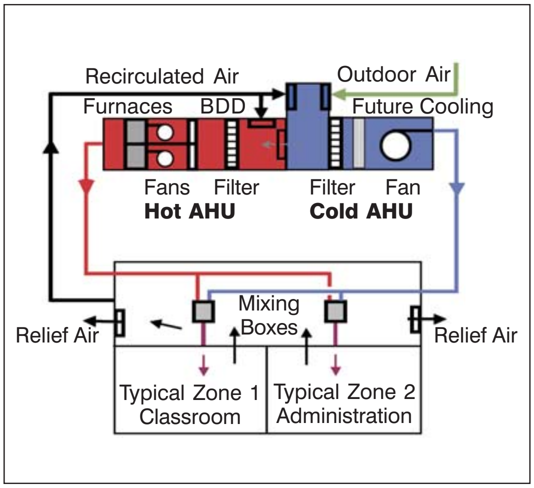

Figure 1: Topham HVAC system.

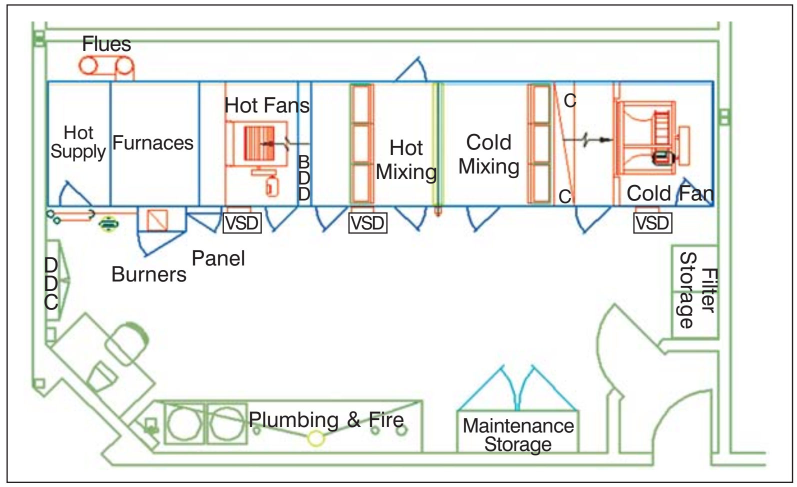

Figure 2: Plant room at Topham.

• Easier maintenance (one ladder position); and

• Gently curved flexible acoustic duct in each diffuser branch attenuates duct-borne noise (*Figure 6*).

Classroom Air Distribution and Heating. Air is supplied through one central diffuser. Normal flow of 5 L/s per m^2 (1 cfm/ft^2) is typical for local schools. Pressing a button on the room temperature sensor for three seconds increases supply to 130% for two hours or until the button is pressed again. (The 30% extra flow required no change in equipment sizing and is available in any zone at any time.)

If cold air enters through the classroom's exterior door, the 30% extra flow from a single central diffuser breaks up stratification by driving supply air across the ceiling and down the walls, leaving the occupied part of the room draft free.

With all air supplied through one diffuser, special care is needed to ensure quiet operation and good air distribution. The diffuser is connected in sheet metal with a straight drop from a bend containing an internal splitter and preceded by straight ducting (*Figure 6*).

Compared to multiple diffusers, the single diffuser offers better heat distribution without drafts and reduces the cost of ducts, connections, dampers, diffusers, and balancing.

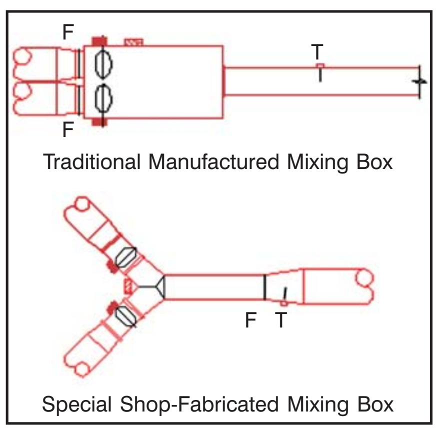

Figure 3: Mixing boxes.

As the system always maintains a high flow rate to occupied spaces, the supply air temperature required for heating is relatively low. The combination of a high flow rate, a low heating supply temperature and diffusers selected for full room coverage helps ensure that all supply air actually reaches the occupants.

Minimum Outdoor Air. Minimum outdoor air enters the cold AHU through a dedicated fixed position damper. This damper acts as an orifice with constant minimum flow being maintained by modulating the recirculating damper to maintain a constant suction pressure as cold AHU flow varies.[1,2]

The minimum outdoor air intake requirement is comparatively low (high ventilation efficiency) for two reasons. First, Topham's single system only needs to cater to the peak occupancy of the school, not the sum of peaks in areas served by different units. Second, a high outdoor air fraction is not needed in the supply air because full zone supply rates are always maintained. When thermal loads are light, the cold supply reduces but the hot duct recirculates "unused" outdoor air[3] from spaces that are empty or lightly occupied.

Minimum outdoor air intake was calculated using a method developed to account for the benefit of secondary recirculation paths like DFDD's hot duct.[1] This is the method from which the equations in Appendix G of ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality,* Addendum *n*[4] were developed.

Assessing the Outcome

Initial Cost. The initial cost of the Topham HVAC system was Can. \$111.95/m^2 (Can. \$10.40/ft^2) in 1999 (then about U.S. \$75.35/m^2 [U.S. \$7/ft^2]). When adjusted for inflation, this was about 30% less than traditional systems and about 10% less than any other system type on which I have been able to obtain data.

Considering DFDD's reputation as a premium quality system, the low cost may seem surprising. The reasons include: one system for the whole school; no boiler plant; heating with air; and cost-effective details (e.g., mixing box and its controls).

Energy Use. *Figure 4* shows heating energy use for Topham and other Langley schools with similar operating hours, similar occupant density and the same code minimum ventilation rate of 7.5 L/s per person (15 cfm per person).

Topham uses *half* as much heat as the next most efficient school and has a 200 MJ/m^2 (17,600 Btu/ft^2) per year Heating BEPI (Building Energy Performance Index). A district energy program improved the efficiency of the other schools, but they still use two to three times as much heat as Topham.

The primary reason for Topham's low energy use is that its DFDD system largely eliminates reheat. Most HVAC systems cool all supply air sufficiently to satisfy the warmest space (either mechanically or with cold outdoor air), and then use a huge amount of energy over the year reheating all or part of the supply for spaces that do not need this degree of cooling.

A second reason is that the outdoor air intake requirement is less (see Minimum Outdoor Air section).

A third reason is that Topham's furnaces are more efficient than any boiler-based system as they eliminate heat losses from boiler casings, piping and standby.

Note that the VAV system in *Figure 4* uses almost as much heat as the reheat systems. VAV systems reduce zone flow to save reheat when thermal loads are low. With less supply for the same number of occupants, VAV zones need a higher outdoor air fraction in the supply air and a larger minimum outdoor air intake. For dense occupancies (e.g., schools) in cool climates, increased outdoor air heating offsets the reheat savings.

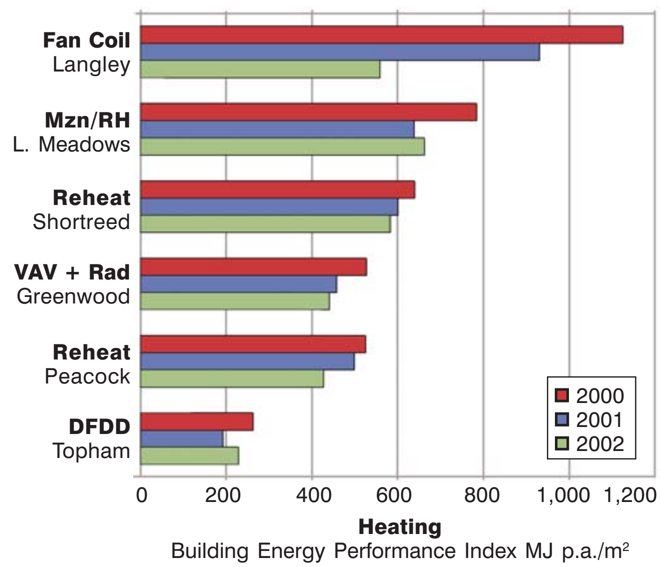

Figure 4: Heating energy use in Langley elementary schools.

No Langley elementary schools have heat pump or heat recovery systems and no data was available from other such schools in the region. It seems unlikely that their energy use would be as low as Topham for the following reasons:

• All heat pumps transfer energy costs from the heating bill to the electrical bill. Water-loop unitary heat pumps can run a compressor to cool a warm space then run a second compressor to transfer this heat to a cool space but DFDD recovers this heat more efficiently, using air that is already circulated for ventilation.

• Heat recovery can reduce the heating load in the cold weather but does not eliminate reheating of cool supply air. If a system needs a lot of reheat to maintain zone temperature control, heat recovery is a bit like applying a Band-Aid to a broken limb—it is not addressing the real problem.

HVAC electrical energy use data is not separately metered. Total building electrical energy use was slightly lower at Topham. No conclusions on relative HVAC energy use can be drawn from this, because total electrical energy use in each school is dominated by lighting.

Fan energy use for DFDD is similar to other systems. Compared to VAV, DFDD moves slightly less air at similar pressure through one AHU, and much less air at much less pressure through the other AHU. Fan coil, unit ventilator and heat pump systems have lower pressures but less efficient fans and a lower power factor.

Thermal Comfort. Feedback from the school on thermal comfort has been very good. All spaces have individual temperature control that maintains temperature to within a fraction of a degree whenever the outdoor air can provide cooling. When the weather is warm, so is the school, but that is the local norm and the teachers appreciate having 30% extra airflow available at the touch of a button. In winter, the system drives warm air down the walls to the floor, breaking up stratification while keeping the occupied part of the room draft-free.

Entrances in Cold Weather. Cold air removal fans coupled with special control of relief air have maintained good conditions at the building entrances although there are no vestibules or entrance heaters.

The cold air removal fans at classroom exterior doors have not been needed (see Classroom Air Distribution section).

Indoor Air Quality (IAQ). Feedback on IAQ from Topham and other facilities with similar systems has been excellent. The following operating characteristics and features help provide both the reality and perception of good IAQ:

• In the mild Vancouver climate, free cooling brings in far more than the minimum outdoor air most of the time.

• Special control is provided for minimum outdoor air (see Minimum Outdoor Air section).

• All zone supply reaches the occupants (see Classroom Air Distribution section).

• The teacher can, at the touch of a button, increase zone airflow by 30%.

• The outdoor air intake is above a sloped roof, well away from potential sources of mold.

• Flue gas is projected vertically and away from the outdoor air intake.

• Acoustic duct lining is limited to large accessible plenums and ducts at the central plant.

• Filter frames, fan capacity and fan control allow "drop in" upgrade to high-efficiency filters.

Quietness. The HVAC system is inaudible outside the school. Inside the school, the DFDD system generally is inaudible

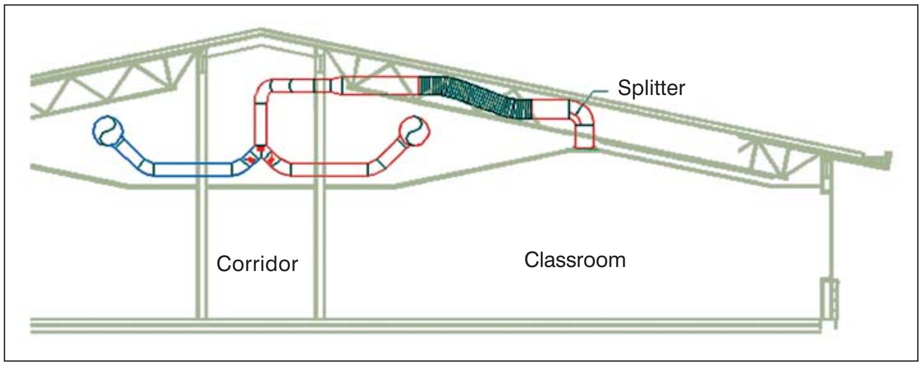

Figure 6: Classroom section.

during occupied hours but perceptible when the school is empty. When the zone airflow is boosted by 30%, air noise is more audible but not to nuisance levels.

No sound level measurements have been made, but the system is so quiet that it is hard to imagine it causing speech intelligibility problems. Future projects could be made even quieter by inexpensive measures such as slightly reducing velocities through diffusers, ducts, and mixing boxes.

Service Life. A long service life is expected as all central equipment is protected from weather in a plant room, service access is excellent, there are no wet systems that could corrode, similar equipment in other buildings has given many decades of satisfactory service, and the system's adaptability and performance make it well suited to handle changing needs.

Reliability. Topham had four mechanical work orders p.a. per 1000 m^2 (11,000 ft^2). The next lowest school had 50% more and the average school had twice as many. Langley's records cover the past two years. They include any service call and do not differentiate between serious problems, minor problems and service calls where no problem could be found.

Factors contributing to Topham's high reliability are:

- The system has very few components;
- Components were selected for reliability; and
- Commissioning was thorough and included actively seeking and eliminating potential future problems.

Maintenance. Over the two years for which data is available, Topham's maintenance cost (Can. \$1/m^2 [U.S. \$8.18/ft^2]) based on time at Can. \$70/hr [U.S. \$53.20/hr]) has been half the average for comparable Langley schools.

The school district advises that Topham's cost is low because little maintenance is needed, and it is concentrated in one easily accessible plant room. Most of Topham's cost has been scheduled filter changes.

Plant Space. At 2% of floor area, Topham's plant room (*Figure 2*) is half the 4% traditionally allocated and even 4% is often not sufficient to house traditional systems.

This small footprint surprises most people, as it seems reasonable to expect DFDD to require more plant space because it requires both a cold AHU and a hot AHU. The surprise increases because the plant room feels spacious yet houses equipment that is sized for future expansion, plumbing equipment, the sprinkler valve station, maintenance storage and a computer workstation. Primary reasons for space efficiency are:

- No boiler room is required;
- The architect cooperated in providing a good plant room configuration with ample headroom; and
- DFDD needs a cold AHU and a hot AHU, however, that is all it needs to efficiently serve the whole facility. Other systems often have far more separate AHUs to serve areas with different hours of operation, occupancies, or load patterns.

Ceiling Space. Due to its pitched roofline and steel open-web joist structure, Topham has ample ceiling space for any HVAC system.

Adaptability to Future Needs

The central plant and primary ducts are sized to handle future addition of up to four classrooms.

Changes in space usage or layout are easily handled by new flow settings or new mixing boxes.

Mechanical cooling is simple to install as the coil space, drain pan, and duct insulation are already in place.

What Explains Topham's Success?

Factors contributing to the good performance and low cost of this form of DFDD include:

- Development of a method to calculate ventilation from secondary recirculation[1] opened the way to box control with no set minimum cold flow and a lower minimum outdoor air intake;
- A new type of mixing box and mixing box control;
- A large "hot" supply (maximizes use of return air to reduce reheat and outdoor air needs);
- High turndown furnaces instead of boiler plant;
- Reducing the number of AHUs by taking advantage of DFDD's ability to efficiently serve areas with different occupancy and hours of use;
- Taking advantage of DFDD's ability to increase zone airflow for more effective heating; and
- Other cost-effective details not limited to DFDD such as single diffusers in classrooms, unducted return air, and design for quiet operation without silencers.

Applying the System Elsewhere

Existing DFDD Installations. DFDD systems have been used in many areas including the Canadian provinces of Alberta, British Columbia, and Quebec, Maryland, Oregon, Utah, Texas and Washington in the U.S. as well as Australia. Applications have included courthouses, hospitals, laboratories, long-term care homes, offices, schools and universities.

Systems in most regions reflect independent local development to address local concerns. The first installations in British Columbia during the late 1970s were developed to provide constant zone airflow relationships, yet save energy in large hospital projects. Recent ASHRAE design award-winning projects in Quebec[2,5] appear to be similar. In California, on the other hand, DFDD systems were developed by design/build contractors who were concerned about the cost of hot water piping and wanted a less expensive alternative to VAV reheat.

Replicating Topham's Results. Simply using DFDD does not guarantee that cost and performance will be the same as at Topham. As much depends upon how DFDD is implemented as the system itself. It does however seem clear that DFDD systems similar to Topham's but with mechanical cooling installed offer significant benefits for a wide range of building types in any climate. Reasons for this are discussed below and in "Dual Fan Dual Duct Systems — Better Performance at Lower Cost."[7] Practical experience over a range of building types and climates has consistently confirmed this.

Building Size Range. The practical size range for DFDD systems is similar to conventional VAV systems. (i.e., from roughly half the size of Topham to the largest of buildings).

Air Conditioning. DFDD is ideal for air conditioning and most DFDD systems are mechanically cooled.

The tonnage required is small because there is no reheat to offset, the single system takes full advantage of diversity, and the high ventilation efficiency reduces outdoor air load. Operating costs are low for the same reasons.

Air conditioning Topham would have been inexpensive as coil space, duct insulation and air-side controls are in place, the climate is mild, the school is not used in midsummer and there were offsetting savings (e.g., computer room air conditioning). Costs elsewhere would depend on climate and other local conditions.

An interesting option used in the D wing at the University of Washington Medical School was to limit air conditioning to selected zones. In summer, zones selected as uncooled closed their cold damper and drew ventilation from the "hot" duct, which supplied unheated outdoor air.

Humid Climates. The following characteristics make DFDD of interest in humid climates:

• In summer, the whole outdoor air intake airflow passes through the cooling coil in the cold AHU.

• The hot AHU recirculates unheated air to temper and help ventilate zones with light thermal loads.

• Outdoor air needs are small due to the high ventilation efficiency.

• Low-temperature air distribution can be used while still providing moderate room supply temperatures and good ventilation without reheat, even in high-occupancy rooms with light thermal loads.

Cold Climates. DFDD's ability to use suitable gas furnaces provides the option to eliminate the risk of freezing a coil and provide the operational security of using a product originally designed for critical makeup air duty at temperatures below –40°C (–40°F).

For cold climate systems with high minimum outdoor air fractions, the outdoor air intake arrangement used at Yucalta Lodge Multilevel Care Facility (*Figure 6*) is better than the Topham configuration as it avoids the need to heat in the cold AHU.

In cold weather, the cold AHU only draws in enough outdoor air to achieve the desired cold supply air temperature. The balance of the minimum outdoor air intake is drawn into the hot unit and heated by the furnaces.

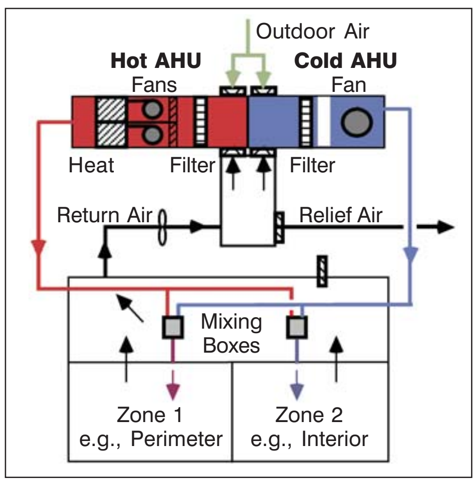

Figure 7: Cold climate, high OA intake.

At Yucalta Lodge makeup air needs were greater than the minimum outdoor air intake needed for ventilation. Outdoor air and recirculation dampers were controlled so that the relief backdraft damper could close but relief plenum pressure was never more than slightly negative.

Where intake is determined by minimum ventilation needs, rather than makeup, it can be controlled from CO_2 concentrations, from flow measurement in a common intake, or from flow measurement at each AHU.

As DFDD can deliver up to 130% of design supply to all perimeter zones at once, it can generally provide good comfort when heating from the ceiling with air in even the coldest climate and eliminate the need for separate perimeter heating in buildings insulated to current standards (compare 130% to 80% for a typical VAV system).

Entrance heating easily can be provided from the hot duct and blown down a wall to floor level. In a cold climate, this would be needed to supplement or to replace the cold air removal fans provided at Topham. Vestibules are, of course, also highly desirable.

Other Building Types. DFDD is applicable anywhere that a central HVAC system can serve multiple zones and a significant amount of air can be recirculated. Typical buildings include: offices, schools, colleges, universities, hospitals, nursing homes, courthouses and penitentiaries.

Where Ceiling Space Is Limited. DFDD systems generally need about the same ceiling space as VAV systems with hot water reheat. DFDD's takeoff crossovers are larger than the insulated pipes of the VAV reheat, but duct mains are smaller and air venting issues are eliminated. Options to save space include using truss space for crossovers, splitting the hot duct into smaller ducts on either side of the cold duct, and arranging the box configuration to suit the space, e.g., *Figure 7*.

Rooftop Equipment. DFDD is easy to adapt to rooftop installations because it does not need boilers and one system can serve the whole building. Although the Topham central plant is indoors to increase service life and provide better maintenance conditions, but it is of a type originally designed for long life in rooftop installations.

Further Energy Savings. Topham's high energy efficiency could be improved further by:

• Demand control of minimum outdoor air intake (supply air CO_2 control can sense the outdoor air content in the supply air and adjust the intake accordingly);

• VAV zone control, with reset of zone minimum flows when free cooling raises outdoor air content in the supply air;

• Reset of minimum supply flow to the gym when it is lightly occupied (gym CO_2 sensing can be used for this purpose); and

• Heat recovery to minimum outdoor air intake from toilet exhaust and minimum relief air.

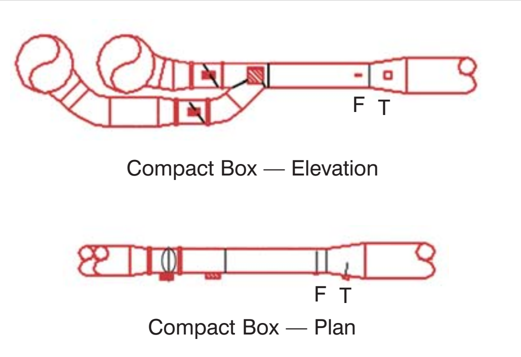

Figure 8: Compact box.

LEED. The efficiency of DFDD systems makes them excellent candidates for LEED projects. For example, the LEED forecast energy use for the system in the academic building, under construction at the University of California, Merced, is 33% of the budget VAV reheat system. This allows the building to earn the maximum 10 points in this category.

Where the System Is Unfamiliar. For mechanical contractors, installation is straightforward with no unproven equipment or unusual installation techniques. As there are fewer items to install and fewer trades are required, there can be some scheduling advantages.

For designers, controls contractors and commissioning agents, there is a significant learning curve. Old ideas must be discarded and new ones learned. To get optimum results, it is important to hire people with the inclination and capability to

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tackle something new, pay them for the time to do it, and provide them with support from those experienced in getting the best value and best performance from DFDD systems.

Operation and maintenance staff will need more initial training than with a familiar system. If the designer, controls contractor and commissioning agent have done a good job then the system should be easy to maintain. If they have not, then operating and maintenance staff will need more time and assistance to fix problems and fine-tune the system than they would need with a system type they know well.

Conclusion

The objectives for this system were unusually ambitious, i.e., to cost less than previous systems, to use less energy, to outperform them in many respects, and to equal them in all other respects.

Gains in some areas often result in tradeoffs elsewhere that may not always be obvious until the system has operated for a few years. Sometimes, however, everything falls into place and this appears to be one of those cases.

The DFDD system at Langley's Topham Elementary School uses half as much heat per unit area as any other system in the district. It has had fewer problems, costs less to maintain and costs less to install. Occupant satisfaction is high and the system rates well on every other identified criterion.

DFDD air-conditioning systems offer an attractive option in any climate for applications where a central system can serve multiple spaces and some recirculation is possible (e.g., educational, offices, hospitals, courthouses). Specific benefits in any particular case will depend upon climate, other local conditions, and the systems being compared with DFDD.

References

1. Warden, D. 1995. "Outdoor air, calculation and delivery." *ASHRAE Journal* 37(6).

2. Krarti M., et al. 1999. "Techniques for measuring and controlling outside air intake rates in variable volume systems." ASHRAE Research Paper TR/99/3

3. ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality.*

4. ANSI/ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality.* Addendum *n*, Appendix G.

5. "1996 ASHRAE technology award winners, Canada's space center." *ASHRAE Journal* 38(3).

6. "2001 ASHRAE technology award winners, Université du Québec à Montréal." *ASHRAE Journal* 43(3):61.

7. Warden, D. 1996. "Dual fan dual duct, better performance at lower cost." *ASHRAE Journal* 38(1).