Ductwork in the Overall Context of Ventilation, Indoor Air Quality and Energy

(SAVE – Duct Seminar, June 10th -11th 1998)

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1.0 Introduction

Ductwork is'an essential component of a ventilation system, since it is the conduit through which air is transported. Commonly it is most usually regarded as a physical component that forms the air transport path linking either the air intake to the zone to be ventilated (supply air) or the ventilated zone to the outlet (extract air). In a wider sense it could also embrace rooms or zones through which the ventilation air flows. For energy efficiency (and noise) ductwork needs to present the minimum of resistance to airflow, yet its size (i.e cross sectional area) is necessarily restricted, by the constraints of space and of cost. The purpose of this presentation is to review aspects of ductwork in relation to the provision of ventilation, air quality issues and energy.

2.0 Provision of Ventilation

Ducting provides an essential conduit for air transport and is, therefore, an integral component of any mechanical ventilation system. As such it has a major influence on ventilation performance, indoor air quality and energy consumption. Furthermore, not only is air transported through ducted systems but, without good design and maintenance, ducts could also carry pollutants, noise, fire and smoke. Optimum performance, therefore, is critically dependent on good design and implementation.

Examples of systems are as numerous as buildings themselves. The key feature, however, is that the ducting must be capable of transporting the air to or from the ventilated spaces as efficiently and as safely as possible. From the point of view of design, this must involve understanding such factors as the building and it's needs, the pressure drop through the system, the acceptable air velocity, and any acoustic and safety requirements.

While almost a universal component for mechanical ventilation systems, ducting increasingly forms part of natural ventilation design. In this instance, though, driving pressures are very small and therefore ductwork needs to present the minimum of impedance to the flow of air. For this reason, it needs to have a relatively large cross-sectional area and should have no tight bends. Typical examples include vertical stacks or shafts for exhaust and straight, horizontal runs for air inlets. A modern example is illustrated in Figure 1 for 'Canning Crescent', a day care centre in London, England. In this example fresh air for offices in the front (polluted) side of the building is drawn through ducting which forms the foundations of the building while supply air for the rear offices comes directly from openable windows. Each office (front and rear) is then served by an individual stack, which is formed as part of the building construction. A further application of the duct is to provide heat exchange of heat to or from the ventilation (and exhaust air) into the thermal mass of the building. This provides for night cooling in summer and general control of the indoor thermal environment in both summer and winter.

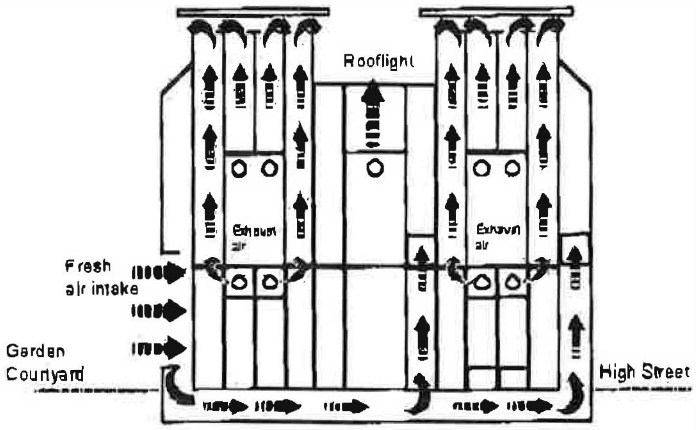

Figure 1 Duct System for Natural Ventilation

3.0 Energy

Energy consumption in buildings accounts for a significant proportion of primary energy use. The relative importance of non-industrial buildings energy consumption (i.e. in dwellings, offices, hospitals, schools etc.) in 13 industrialised countries (i.e. Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, and the United States) as compared to other energy sectors is summarised in Figure 2. This shows building energy demand to be of comparable significance to the transport sector and more than twice that of industrial demand (Orme 1998). Of this, as much as 50% is dissipated from the building in the departing air stream.

As buildings become more thermally efficient, the proportion of energy loss (either heating or cooling losses) associated with ventilation and air infiltration is expected to become the dominant thermal loss mechanism. It is therefore essential to understand the role that ventilation plays in contributing to energy loss and to identify methods to improve the energy efficiency of ventilation. In addition to the actual energy dissipated by airflow, the motivational energy of ventilation also has considerable impact on energy performance. Relative values are summarised in Figure 3. As an approximate guide, current best practice performance could be expected to operate at 1 Watt for each litre/second of airflow (W/l.s). Inefficient systems or poorly designed systems may operate at levels greater than 3W/l.s. It also must be remembered that this reflects the delivered (electrical) energy demand. If electrical energy is generated from fossil fuel, the primary energy impact is substantially greater.

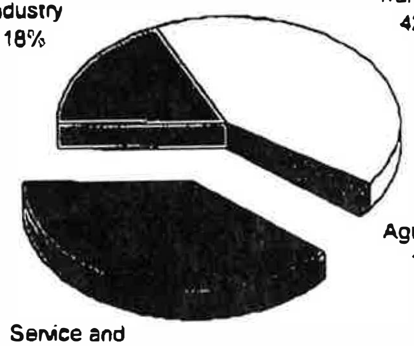

Figure 2 Energy Consumption in Buildings (AIVC Countries)

Ducting influences energy impact in two senses. First the motivational energy needed to drive air through the ducts and secondly, the loss of conditioned air into non conditioned spaces through duct leakage. Duct leakage too can result in the discharge of contaminated exhaust air back into occupied zones.

Motivational energy is provided by the fan. Essentially, energy consumption is dependent on the flow rate, pressure drop across the system, fan efficiency and motor efficiency. Fan power is approximately proportional to the cube of the air velocity. This means that halving the flow of air through a duct will result in an eight fold decrease in fan power. Large cross-sectional area ducting can therefore be beneficial but must be assessed in terms of additional capital costs and space needs.

The duct itself imposes a resistance to airflow that manifests itself in terms of a pressure drop. The greater the flow resistance, the greater is the fan capacity and electrical energy that is needed to drive a mechanical ventilation system. The amount of resistance depends on:

- The airflow rate required;
- The cross sectional area of the duct;
- The length of the duct run;
- The number of angles and bends;
- Surface roughness
- Impedences presented by filters, cooling coils and other obstructions.

Ducting which passes through unconditioned spaces should be well insulated to prevent heat loss and airtight to prevent the loss of conditioned air itself. In fact the airtightness of ducts has generally been shown to be very poor. This topic is summarised in further detail in Section 4.0.

By means of a case study, it is possible to demonstrate the large impact that careful planning of the duct system can achieve. In this example, Jagemar et al (1996) describes the steps achieved to reduce the fan power needed to drive the ventilation system serving a large hospital from 4W/l.s to measured values of between 1.63 and 1.86 W/l.s. All the reductions were achieved on a cost effective basis.

In Europe, as part of the JOULE 'NatVent' Programme the development of high efficiency fans is taking place. These are intended to assist natural forces without incurring an excessive energy penalty. The first application is in an air to air heat recovery unit in which system energy is ¼ W/l.s (Skaret et al 1998).

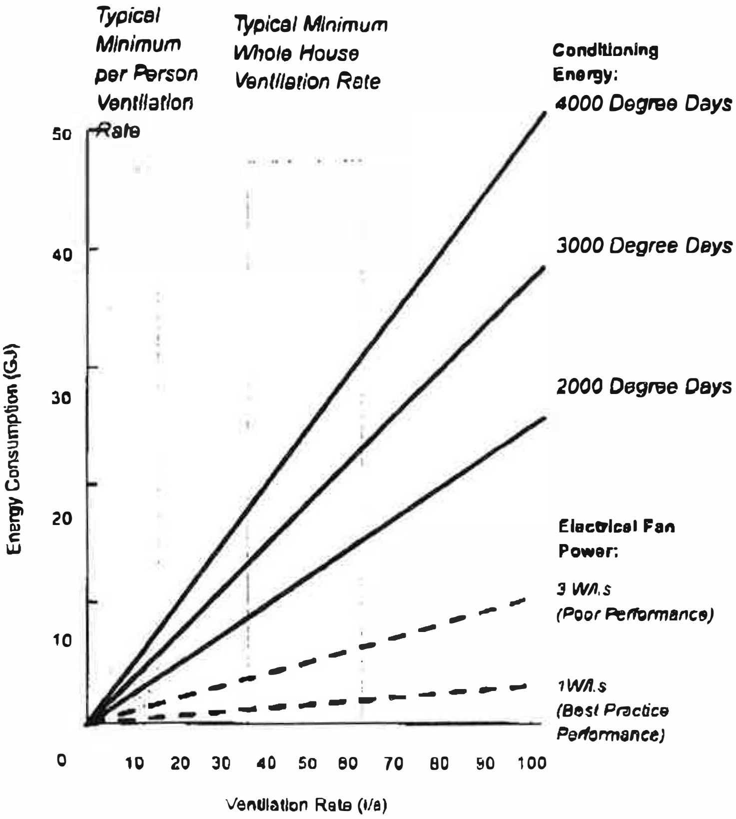

Figure 3 Energy Impacy of Ventilation

4.0 Duct Leakage

Energy aspects of duct leakage in Europe have recently been reviewed by Carrie et al (1997). Essentially this study revealed the probability of excessive energy losses combined with a general lack of data for many countries. This study resulted in the initiation of the present European SAVE-DUCT Programme.

In the United States, considerable work has been undertaken to evaluate the performance of ducted warm air systems in homes. Hammon et al (1996) for example, describes a co-operative project between the building industry, environmentalists, researchers and regulators to develop cost effective procedures for duct system design. An estimated 12% heating and cooling energy saving is seen as possible by simple duct sealing measures costing $250 for each home. Roberson et al (1997) report on the approaches to ducted systems needed for four different climates within the United States (i.e. cold, mixed, hot-humid and hot arid). For mixed cold and hot,

hot-humid and hot arid climates ducted supply ventilation is recommended since this offers the benefits of the ability to filter and dehumidify ventilation air. When combined with forced air conditioning it is recommended that ductwork is installed within the conditioned space. In cold climates the option of heat recovery is recommended.

Walker et al (1996) have made studies on existing dwellings and have shown that duct sealing can reduce energy consumption by 10%. Similarly, Withers et al (1996) illustrate the savings potential of retrofit in eighteen commercial buildings. In most cases the remedial action concentrated on improving the airtightness of the ductwork. Cooling energy was reduced by an average of 15.1%, resulting in a saving in running costs of $195/year at an average repair cost of $455.

In Canada too, analysis of duct systems has been taking place. Allen (1996) reports on improved forced air systems strategies on behalf of the Canada Mortgage and Housing Association. Recommendations include the use of shorter ductwork, implementation of duct sealing measures and the incorporation of variable flow high efficiency fans.

5.0 Air Quality Issues

An important concern, is the issue of air quality. It is essential that ducting does not taint the air and contribute to its contamination. Supply air ducting can transmit pollutants directly to building occupants. Similarly poorly maintained and leaky extract ducts can recirculate pollutants back into the building. Clean ducting, therefore, is one of the preconditions of good indoor air quality. Several studies have investigated the contamination of ducts. Fransson et al (1995) report on methods for sampling contaminants and consider a calculation technique for predicting particle deposition inside ductwork. This work demonstrates the coupling between surface contamination and the concentration of contaminants in the air. Torkki et al (1996) report on a study of the sensory and chemical emission rates of ducted supply air. They investigated ducts with different levels of contamination at different temperatures, humidities and airflow velocities. They tested two new duct systems and a twenty year old uncleaned system. Of the new networks one was tested after cleaning with duct cleaning solvent and the other was left untouched after the point of manufacture. Odour testing showed that flow rate had a significant influence on contamination levels of both the old duct and the uncleaned new duct. In both instances contamination increased with increasing flow rate. The newly cleaned duct had an opposite effect indicating that pollutants were being adsorbed on to the clean surface. Temperature and relative humidity was found not to have a significant effect on contamination.

The need for duct cleaning to achieve good quality ventilation air was clearly emphasised. Kalliokoski et al (1995) indicated how dust and micro-organisms found in even new ductwork can contaminate supply air. In a study of 14 Finnish office buildings they concluded that there was 13.2 g/m2 of dust and the annual accumulation rate averaged 1.2 g/m2. The average count of viable fungal spores amounted to 3370 cfu/g. Further analysis of the accumulation of fungi in air ducts is reported by Pasanen et al (1997). They report on investigations in twenty four single family homes with balanced (supply and exhaust air) ventilation. Fifteen of these homes were heated by warm air central heating Dust was collected from the ducts simultaneously with cleaning of the ventilation systems. Besides spore concentrations and flora of culturable fungi, total fungal spore concentrations were also determined. Total spore concentrations varied between 10^{-7} and 10^{-8}/g of dust, whereas culturable spores amounted to less than 5% of the total spore count. Similar total fungal concentrations were found in both the supply and extract ducts but culturable spore concentrations tended to be higher in the extract ducts.

Flaig (1995) reports on the significance of dust deposits in ducts and quotes research figures of contamination levels of between 6.8 to 18.2 g/m^2. This he compares with Swedish guidelines of 1 g/m^2 for a good standard of hygiene.

6.0 Noise

Without careful design, ductwork can transmit excessive noise, thereby causing disruption and discomfort to occupants. Much research therefore has focused on the issue of inhibiting noise. Op't Veld et al (1996) presents a comprehensive background to this topic and reviews noise in relation to three categories:

- Outdoor noise entering through the ventilation system (e.g. through cracks, mechanical supply and exhaust openings etc.);
- Noise generated by components of the ventilation system;
- The impact of ventilation systems on sound penetration between partitions (cross-talk brought through the duct system and ventilation openings in the partitions).

Various tools and calculation techniques are described for evaluating the emission and control of noise and the sizing of acoustic components (silencers).

De Salis et al (1996) concentrate on the reflection of acoustic waves caused by in-duct obstructions. From their analysis, they have developed a simple relationship between pressure loss coefficient and the acoustic reflection coefficient that can be used for commissioning and/or the control of a mechanical ventilation system.

'Active' sound control is proving to be an effective technique for reducing the intensity of sound emitted from supply openings into spaces. Essentially the sound at the emission point is monitored and neutralised with a matching, out of phase component. A review of active noise control systems is presented by Brister 1993.

For further information, a comprehensive bibliography of ventilation and acoustics has been produced by the Air Infiltration and Ventilation Centre (Limb 1997).

7.0 Standards

Concern over the contamination of air in ducts has culminated in the progression of various standards, codes of practice and requirements for ducted systems. The European Work Place Directive, for example, specifies the need to take into account the internal conditions of ducts. All new systems must allow access to ducts for cleaning and maintenance. One of the problems with cleaning existing systems has proved to be gaining access. Sometimes, as much as half or more of the cleaning cost being associated with such access. Further details, specifications and information about cleaning ventilation systems to meet the European Directive are presented by the UK Building Services Research and Information Association (Loyd 1994, 1996). Also, in the United Kingdom, the Heating and Ventilation Contractors Association has introduced guidelines for the cleanliness of new ducts (DW/TM2, HVCA\1991). Further work is aimed at developing guidelines for the cleaning of existing ducts.

The Nordic Committee on Building Regulations (NKB 1991) has prepared recommendations for its five member countries (Denmark, Finland, Iceland, Norway, Sweden). These specify that:

- Outdoor air intakes shall be placed where the air admitted is likely to be cleanest;
- The spread of airborne pollutants in the room and to other rooms shall be limited (Encapsulation, hoods, local extraction etc.);
- Every workroom and habitable room shall be provided with an openable window;
- It shall be possible for both supply and extract systems to be cleaned in their entirety;
- Drawings and specifications shall be produced;
- Systems shall be regularly inspected.

In Sweden regulations are in place to ensure the regular inspection of mechanical ventilation systems in most buildings (Granqvist et al, 1994). Inspection schedules vary from between 2 and 9 years.

In the United States, Brooks (1995) provides key design guidance covering not only duct layout and sizing issues but also information concerning fire and smoke control. Duct maintenance needs are also covered by ASHRAE Standard 62 (1989 – under revision). Guidelines in the intended revision include:

- Inspection and maintenance records;
- Responsible maintenance manager;
- Visual inspection of all major air handling components;
- Filter replacement at least twice yearly;
- Annual inspection of outside air dampers and actuators;
- Annual inspection of ceiling return plenums;
- Annual inspection of heating and cooling coils, cleaning as necessary;
- Annual inspection of drain pans;
- Measurement (and adjustment) of flow rates on renovation or at 5 year intervals.

8.0 Conclusions

Ductwork has a considerable impact on the performance of ventilation systems. This summary has attempted to outline some of the key issues, especially in relation to ventilation, energy and indoor air quality. Of significant importance is how poor design and maintenance can contribute to the contamination of supply air and result in unnecessary energy consumption.

Duct systems must be designed with cleaning and maintenance in mind. Mechanical systems should aim for energy consumption in the region of 1W/l.s of air flow or less for good energy efficiency. Except for very special applications, systems operating above 3W/l.s are of poor energy efficiency.

9.0 REFERENCES

Allen Associates "Optimising residential forced air systems", Canada Mortgage and Housing Corporation November 1996.

ASHRAE\Standard 62, "Minimum ventilation for acceptable indoor air quality", 1989 (currently being revised).

Brister A, "The sound of silence", Buidling Services (UK) July 1993.

Brooks P J, "duct design fundamentals", ASHRAE Journal (US), April 1995.

Carrie F R, Wouters P, Andersson J, Faysse J C, Chaffois P, Kilberger M, Patriarca V, "Impacts of air distribution system leakage in Europe: the SAVE duct programme," AIVC 17th Annual Conference, Proceedings, Athens 1997.

De Sallis M H F, Oldham D J, and Levermore G J, "Application of acoustic techniques to the commissioning and control of mechanical ventilation systems", CIBSE/ASHRAE Joint National Conference, Proceedings, Harrogate UK, 1996.

Flaig K, "Dust in the duct", Clima Comm. International, March 1995, Vol 20 No 4, 1995.

Fransson J I, Ruud S H, Rosell L, "Clean ventilation ducts", Swedish National Testing and Research Institute, SP Report No 1995:38, 1995.

Granqvist P, Kronvall J, "Checking the performance of ventilation systems, the Swedish approach", Air Infiltration Review, Vol 15 No 2, March 1994.

Hammon R W, Modera M P, "Improving the energy efficiency of air distribution systems in new homes," ACEEE Summer Study on Energy Efficiency in Buildings, Proceedings, Washington, 1996.

Jagemar L, Andersson L, "Design and commissioning of an energy efficient air distribution system in a university hospital," ACEEE Summer Study on Energy Efficiency in Buildings, Proceedings, Washington, 1996.

Kalliokosko P, Kujanpaa L, Pasanen A-L Pasanen P, "Cleaning of ventilation systems and its effect on air change rates in single family houses", Healthy Buildings '95, Proceedings, Milan Italy 1995.

Limb M, "Ventilation and acoustics – an annotated bibliography", AIVC 1997.

Loyd S, "Ventilation system hygiene - a review", Technical Note TW 18/92.5, 6th edition Building Services Research and Information Association (BSRIA), May 1994.

Loyd S, "Ductwork cleaning specification for facilities managers", CIBSE/ASHRAE Joint National Conference, Proceedings, Harrogate UK, 1996.

NKB, "Indoor climate – air quality", Nordic Committee on Building Regulations, NKB Publication No. 61E, 1991.

Op't Veld P, Passlack-Zwaans C, "IEA Annex 27: Evaluation and demonstration of domestic ventilation systems", AIVC 17th Annual Conference, Proceedings, Gothenburg Sweden, 1996.

Orme M, Energy Impact of Ventilation, AIVC Technical Note 49, ISBN 1 946075 97 2, 1998-06-01, 1998.

Pasanen A L, Kujanpaa L, Pasanen P, Kalliokoski P, Blomquist G, "Culturable and total fungi in dust accumulated air ducts in single family houses", Indoor Air '97, Proceedings, 1997.

Roberson J A, Matson N E, Brown R E, Koomey J G, " Recommended ventilation strategies for new energy efficient production homes", AIVC 17th Annual Conference, Proceedings, Athens 1997.

Skaret E, Blom P, Brunsell J T, "Energy recovery possibilities in naturally ventilated buildings", NatVent Work Package 3.3 1998 (to be published).

Torkki A, Seppanen O, "Olfactory and chemical emissions of ventilation ducts", Indoor Air 1996, Proceedings, Nagoya Japan, 1996.

Walker I S, Modera M P, Tuluca A, Graham I, "Energy Effectiveness of duct sealing and insulation in two multi-family buildings", ACEEE Summer Study on Energy Efficiency in Buildings, Proceedings, Washington, 1996.

Whithers C R, Cummings J B, Moyer N A, Fairey P W, McKendry B B, "Energy savings from the repair of uncontrolled airflow in 18 small commercial buildings", ASHRAE Trans. Vol 102 Pt 2, USA, 1996.