ENERGY AND VENTILATION

M. W. Liddament and M. Orme

Air Infiltration and Ventilation Centre
Sovereign Court, Sir William Lyons Road
COVENTRY, CV4 7EZ
Great Britain
Tel +44(0)1203 692050
Fax: +44(0)1203 416306
email: airvent@aivc.org

ABSTRACT

The energy statistics of OECD Countries shows that between 30-50% of primary energy is consumed in non-industrial buildings (i.e. in dwellings, offices, hospitals, schools etc.) 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. Additional losses may be associated with the energy needed to operate mechanical ventilation systems. It is therefore essential to understand the role that air change plays in contributing to energy loss and to identify methods to improve the energy efficiency of ventilation. Much of this area of activity is still on-going but the purpose of this paper is to present an overview of the current level of understanding and summarise the results of recent analytical work. Taking the building stock as a whole, the present analysis shows that airchange accounts for approximately 36% of total space conditioning energy and contributes to almost half of heating equipment losses. If fresh air supply was controlled to meet current recommended ventilation rates for health, then it is estimated that ventilation heat energy could be reduced to a quarter of its present value.

Keywords: - Energy impact, ventilation, air infiltration.

INTRODUCTION

Ventilation is essential for the maintenance of good indoor air quality. However, despite its essential need, there is much evidence to suggest that energy loss through uncontrolled or unnecessary air change is excessive and that much can be done to minimise such loss. Considerable losses may also be associated with ventilating pollutants that can be more effectively controlled by their elimination at source. Air infiltration exacerbated by poor building airtightness adds further to lack of control and energy waste.

- The relative importance of building energy consumption 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 1. This shows building energy demand to be of comparable significance to the transport sector and more than twice that of industrial demand. To understand the 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.

ESTIMATING ENERGY IMPACT

To estimate energy impact, it is necessary to know:

- the mass flow rate of air from the inside to the outside of the building;
- the difference in enthalpy between the incoming and outgoing air masses.

While, conceptually, this is a straight forward calculation, in practice it is an exceedingly difficult exercise to undertake, especially on a macroscopic scale (i.e. representing the building stock as a whole). This is mainly because so little is known about the mass flow rate of air through each building. Because of these uncertainties, it is necessary to base estimates of energy impact on indirect assumptions about ventilation rates and climate. Confidence is improved by applying a variety of essentially independent methods and analysing the areas of agreement or overlap. This approach is described in further detail in the following sections. An example of the energy impact of air change for various demands and climatic conditions [2] is illustrated in Figure 2. The first shaded area represents the typical per person rate of ventilation that is applied to office spaces, while the second is representative of a whole house value. Included in the picture is a typical band of additional fan energy needed to meet these ventilation rates by mechanical fans.

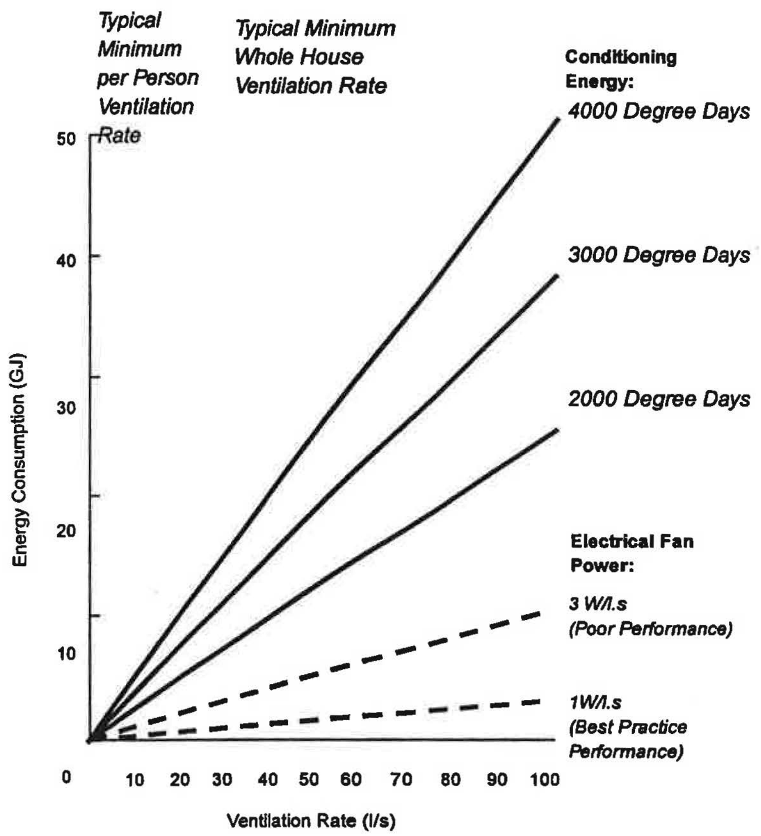

Figure 2 Examples of the Energy Impact of Ventilation

significance of the energy impact of air change, the AIVC has been undertaking a study of curre estimates for non-industrial buildings (residential buildings, offices etc.) It has also been reviewii the potential for energy reduction by improved ventilation control. Individual country aspects the study are still on-going but an overall picture is emerging. This paper reports on tl mechanisms and thinking behind this study and outlines the initial results.

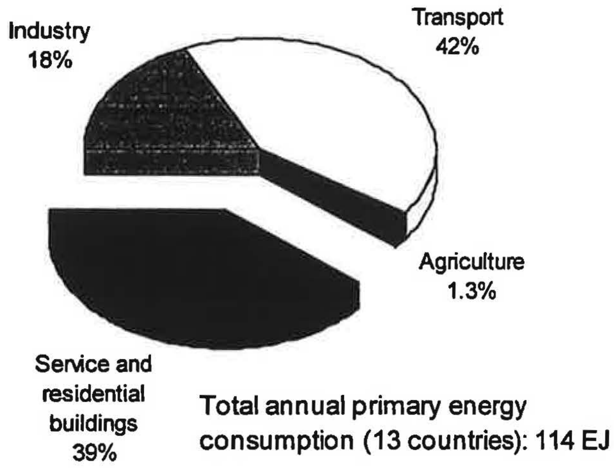

Figure 1 Primary energy shares of the major energy using sectors

AIRBORNE ENERGY LOSS

It is important to recognise the structure of airborne energy loss and to identify the related method: control. In essence there are three distinct types of losses; these are:

- Venting of Waste Heat: excess heat is often developed inside buildings. Examples include generation of heat from office equipment and cooking appliances, and gains from solar radiat While such waste heat or 'incidental' gain can sometimes be used beneficially in the Winte may also contribute to the need for refrigerative cooling at other times. Minimising waste heat is dependent on improving the energy efficiencies of appliances and processes.

- Flue Emissions: much airborne heat is lost through combustion flues. Condensing appliaı provide a means for capturing some of this waste. Flues and chimneys that are open to ro provide a further uncontrolled route for air escape even when the appliance itself is not in use.

- Loss of Thermally Conditioned Air: this is associated with the loss of intentionally conditi((heated or cooled) air from a space by ventilation or air infiltration. It is an assessment of particular aspect of airborne energy loss that forms the basis of this paper.

An additional consideration is the fan energy associated with the mechanical distribution of Recent research [1] has been focusing on this topic. As an approximate guide, current best pra performance could be expected to operate at 1 Watt for each litre/second of air flow (W Inefficient systems or poorly designed systems may operate at levels greater than 3W/l.s. It also

ESTIMATING MASS FLOW RATE

For the reasons described above, a general method of estimating the energy impact of air change must be based on very broad assumptions about climate and the mass flow rate of air. In undertaking this study the results from various methods have been used to infer the mass flow rate of air through buildings; these include:

- ***Direct Measurement***: The direct measurement of air change rate by tracer gas would provide the ideal approach. However it can only really be applied to a minuscule number of buildings. Nevertheless, existing data provides some indication of expected values. Air leakage testing by pressurisation combined with typical weather data also provides guidance on what to expect.
- ***Estimating Average Air Change Rate:*** This is based on using available data to estimate a typical band of air change rates for each category of building. For example, measured air change rates in many types of buildings vary from approximately 0.5 to 1.0 air changes/hour (ach). The total mass air flow rate for a particular building stock is calculated by multiplying the total number of buildings by the average volume and then by the estimated upper and lower air change value.
- ***Estimating ventilation rate on a per occupant basis:*** Frequently ventilation needs are expressed on a per occupant basis, especially for office buildings. This again, gives a basis for inferring a general value. This approach has been developed further in a comprehensive study of the Swedish housing stock [3]. Detailed measurements made on a statistically representative subset of the housing stock shows that the per person ventilation rate amounts to between 12-18 l/s.p. The overall flow rate for each building sector is determined by multiplying the occupying population size by the per person flow rate.

ENTHALPY AND DRY BULB TEMPERATURE DIFFERENCE

Enthalpy difference represents the change in energy content of the air between the incoming and outgoing (thermally conditioned) air streams. In the heating mode, in which no change is made to the moisture content, enthalpy difference becomes proportional to the dry bulb temperature difference. Under conditions of refrigerative cooling, in which moisture is extracted from the air, or during humidification, during which moisture is added to the air, the latent heat change of the air must also be incorporated into the enthalpy calculation. Again, very broad assumptions about typical indoor climate conditions and about the outdoor climate must be made. Methods include:

- ***Direct Measurement***: The measurement of indoor and outdoor thermal parameters can be made on an individual building basis without much difficulty. Data for specific buildings serve as an indicator of the validity of general results.
- ***Degree Days:*** Degree day data provides one method for tracking thermal variations. In essence, for heating climates, it is the number of degrees of temperature difference, averaged over a one day period, that the outdoor temperature is below a given base temperature. In climates in which cooling and dehumidification of the incoming air is necessary, a similar concept is applied to quantify the enthalpy of the air above a given base temperature and moisture loading. An advantage of the degree day approach is that the 'base' temperature is usually selected to allow for 'free' heating from incidental gains. In other words it reflects the actual temperature to which space conditioning is needed.
- ***Average Temperature Difference:*** Sometimes an average temperature difference between the inside and outside of the building is applied[4]. This is based on the difference between an assumed indoor air temperature and the average seasonal (daily or monthly) outdoor temperature.
- ***Hourly 'Bin' Data:*** Hourly weather data may be used for more detailed information about the energy impact of ventilation by enabling a succession of estimates to be made over a period on an

hour by hour basis. Data are sorted into a matrix or 'bins' representing the number of hours that specific thermal conditions occur. An example of its use is described by Colliver [5] who applied this approach to estimate the energy needed to condition each kg/h of incoming air to specific heating and cooling set points for various cities throughout Europe and the Unites States.

ENERGY BALANCE ANALYSIS

An alternative method of estimating the energy impact of air change is to undertake a complete energy balance evaluation of the building. Very often the 'deficit' between known gains and fabric and other losses is assumed to be directly attributable to airborne loss. Typically such deficits are found to be between 30%-50% of conditioning energy. This approach provides a useful independent check against other evaluation methods (i.e. air change energy should be expected to fall close to the band predicted by energy balance).

RESULTS

An example of the application of these various methods, based on data about the UK housing stock [4] is illustrated in Figure 3.

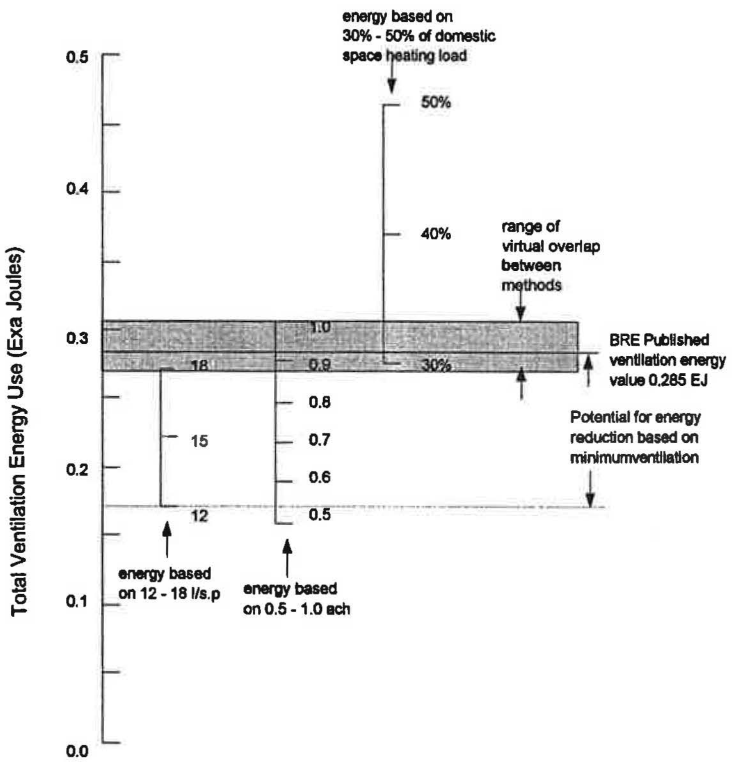

Figure 3 Comparison of Evaluation Techniques

Methods applied included:

- air flow rate estimation of 0.5 - 1.0 ach per dwelling;
- air flow rate estimation of 12-18 l/s.p;
- climate of 2500 degree days;
- an energy balance of 30 - 50% of delivered space heating energy.

- an independent evaluation based on knowledge about average indoor and outdoor air temperatures [4].

The results show a very narrow band of close overlap which was found to be consistent with the independent result and best available information about the housing stock. For this particular set of results there is considerable potential for reducing energy loss while still maintaining an acceptably high level of ventilation (e.g. 12 l/s.p would result in a saving of about 33%).

By applying a similar approach to both the housing and non-residential building stock of all thirteen countries it has been possible to estimate total airchange loss as a proportion of other losses as illustrated in Figure 4.

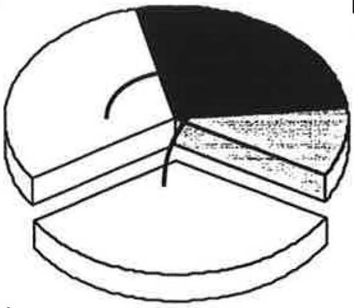

Figure 4 Dissipation of Delivered Space Conditioning Energy in the Service and Residential Sectors

It is interesting to note that air change heating losses (purely arising from the loss of enthalpy) seem to be as important as other forms of energy loss. This, of course, is only an approximate guide, due to the large number of assumptions that have been made in order to deduce this result. Heating air change and conduction losses are both associated with a proportion of the heating equipment losses. So, a reduction in one of these will cause a proportional drop in heating equipment losses. Other studies have also been carried out for the service and residential sectors that provide an indication of the magnitude of energy consumption due to air change. For example, VanBronkhorst et al [6] have estimated that air infiltration alone accounts for roughly 18% of the heating load in all office buildings in the USA. Also, Herring et al [7] state that ventilation accounts for 20% of the energy losses in UK service sector buildings. A comprehensive study of ventilation energy impact has also been made by Sherman et al [8].

REDUCING AIR CHANGE RELATED ENERGY LOSS

At the present time, it is not possible to estimate accurately by how much the energy consumption associated with air change may be reduced, on account of the large uncertainties and deficiencies in essential data. Ultimately, once the service and residential building characteristics have been determined, the most important quantities that will remain to be established are the average air change rates. (These are needed to calculate the volume of air that must be heated or cooled every year.) These may be deduced perhaps through either large-scale measurement programmes, or through modelling representative building types for each country. Subject to the above caveats, it has still been possible to derive an approximation of the extent by which air change energy consumption may be reduced. For example, if the ASHRAE Standard 62 guideline [9] (ASHRAE 62-1989R, Public Review Draft, August 1996) were to be universally followed, it is conceivable that air change heat losses may be reduced to one quarter of the current level (not allowing for reduced equipment losses). The assumption that fresh outdoor air is only supplied on the basis of occupant requirements, as stated in this Standard, is the basis of Figure 5. It has also been assumed that ventilation air is supplied continuously throughout the year, for each of the service and residential sectors. The upper long-dashed line on the graph shown in Figure 5 depicts the current total delivered air change related energy consumption. This total is equal to the sum of the estimated heating air enthalpy change losses with the associated fraction of the heating equipment losses. The lower continuous line indicates the level to which the current total could theoretically be reduced, for given outdoor air supply rates per occupant. The 'ASHRAE 62' reduction is shown by the short-dashed vertical line at the 7.5 litres per second per person level.

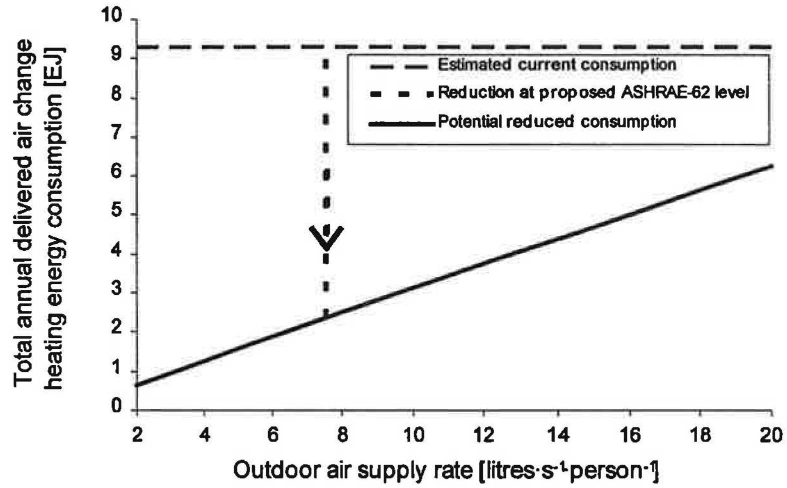

Figure 5 Potential delivered air change energy saving for the service and residential sectors (13 countries)

Sufficient ventilation must always be provided to satisfy the health and comfort needs of occupants. Such requirements are the subject of Standards, Regulations, and Codes of Practice (e.g. ASHRAE Standard 62). Minimum levels normally take into account metabolic needs, and pollutant loads. In addition, considerably greater amounts of air change may be necessary to satisfy cooling needs when mechanical cooling is not used. Practical measures for the reduction of air change energy consumption would be linked to:

- avoiding unnecessary air change (i.e. dealing with leaky buildings);
- introducing good control strategies (for example to avoid the use of window and door opening during periods of active cooling or heating);
- minimising the heat load during cooling periods to restrict excessive heat gains,
- optimising fan efficiency;
- optimising other equipment efficiencies (such as heating equipment), and
- the introduction of guidelines indicating expected best levels;

However, barriers still remain concerning the adoption of such measures. For example, there is ‹
a conflict of interest between building owners who would pay for them, and building occupiers
would benefit from reduced energy expenditure.

Heat recovery systems also offer a route to further ventilation related energy saving. How
additional electrical demand is necessary which needs to be translated back to impact on pri
energy use. As with all evaluations a total energy evaluation is needed to assess the benefit. I
case of heat recovery, this has to involve a full understanding of the implications of air infiltratio

CONCLUSIONS

1. Infiltration and Ventilation account for a significant proportion of energy use in buildings. paper reports early findings from a major study into estimating the full impact of airchang building energy use.
2. Taking the primary non industrial building stock of 13 major industrialised countries, the airchange energy demand is estimated to amount to 36% of space conditioning energy contributes to almost half of heating equipment losses.
3. If air were provided to meet currently accepted standards for ventilation, energy demand cou reduced to as little as a quarter of the present value. Should higher rates of ventilation be req there is still substantial opportunity for reduced energy demand.

REFERENCES

[1] Jagemar L., Design of Energy Efficient Buildings Applied on HVAC Systems in Comme Buildings. PhD Thesis, Chalmers University, Gotheburg, 1996.

[2] Liddament M.W., A Guide to Energy Efficient Ventilation, Air Infiltration and Ventilation C 1996.

[3] Norlen, U, Andersson K, The Indoor Climate in the Swedish Housing Stock, Swedish Counc Building Research Document D10: 1993

[4] Shorrock L.D., Henderson G., Bown J.H.F., Domestic Energy Fact File, UK Building Res Establishment, 1992.

[5] Colliver D., Energy Requirements for Conditioning Ventilation Air, AIVC Technical Not 1995.

[6] VanBronkhorst D A, Persily A K, and Emmerich S J (1995), "Energy Impacts of Air Leaka US Office Buildings", *Proceedings of the 16th AIVC Conference*, Volume 2, pp. 379-391, Springs, CA, USA.

[7] Herring H, Hardcastle R, and Phillipson R (1988), *Energy Use and Energy Efficiency ir Commercial and Public Buildings up to the Year 2000*, UK Department of Energy, HMSO. #325

[8] Sherman M., Matson M., Ventilation Energy Liabilities in US Dwellings, Proc 14th Conference, Energy Impact of Ventilation and Air Infiltration 1993.

[9] ASHRAE 62-1989R, Ventilation for Acceptable Indoor Air Quality, Public Review Draft, A 1996.