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ESTIMATES OF THE ENERGY IMPACT OF VENTILATION AND ASSOCIATED FINANCIAL EXPENDITURES

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ABSTRACT

Ventilation is essential for the maintenance of good indoor air quality, although there is evidence to suggest that energy loss through uncontrolled or unnecessary air infiltration is excessive. In this study, estimates are presented for air change (ventilation and infiltration) energy use in non-industrial buildings for 13 countries. Various methods are used for the estimates, but they are mainly based on calculating the total annual enthalpy change needed for the conditioning of air. The potential for reduced energy use by improved ventilation control is also briefly reviewed. In addition, estimated financial expenditures associated with this energy use are indicated. These are derived from the air change energy estimates using published International Energy Agency (IEA) energy pricing information. Considering the non-industrial building stock of the 13 countries collectively, the total annual loss of heating energy due to air change is estimated to amount to 48% of delivered space conditioning energy (including heating equipment losses). The results emphasise that air change related energy losses are as important as conduction and equipment losses (including 'flue' losses) in dissipating delivered space conditioning energy from buildings.

KEYWORDS

Energy use, national energy balances, ventilation, air infiltration, financial expenditure

1. INTRODUCTION

Although ventilation is essential for the maintenance of good indoor air quality, there is evidence to suggest that energy loss through uncontrolled or unnecessary air infiltration is excessive. Therefore, it is important to quantify present energy use, so that possibilities for energy conservation may be investigated. The objective of this paper is to present estimates of annual air change energy use and the associated annual financial expenditures attributed to the service and residential building sectors of 13 industrialised countries. The countries considered are: Belgium (BE), Canada (CA), Denmark (DK), Finland (SF), France (FR), Germany (D), The Netherlands (NL), New Zealand (NZ), Norway (NO), Sweden (SE), Switzerland (CH), UK, and USA. ('Air change' refers to the combination of ventilation and infiltration related air flows.) Estimates of what are 'reasonable' values for the normalised air change energy use in each country are presented. In addition, the potential for reducing air change related energy losses is briefly discussed. A more extensive description of this work can be found in Orme (1998), of which this paper (excluding the financial aspects) forms a summary.

1.2 Definitions

The service sector consists of buildings used for commercial or public purposes, while the residential sector consists of both single family dwellings and flats. Primary energy is defined by Schipper and Meyers (1992) to be the sum of energy utilised directly by end-users (known as delivered or final energy) and the energy lost in the production and delivery of energy products. The aggregated total annual primary energy use for the 13 countries is 114 EJ, with approximate shares for each sector (based on IEA, 1996): industry - 18%; transport - 42%; agriculture - 1.3%; service and residential buildings - 39%. Non-industrial (i.e. service and residential) buildings can be seen to be very significant users of primary energy. Furthermore, the residential sector uses almost double the primary energy compared to the service sector. The energy content of air is known as enthalpy. So, estimates of air change energy use can be made from the absolute value of the difference in specific enthalpy change [$J \cdot kg^{-1}$] between the supply air before and after conditioning. This is equivalent to evaluating the required sensible and latent heat changes to the air. This energy use is then called the air enthalpy change [J]. In addition, in order to convert an enthalpy change to delivered energy (and vice versa), an average efficiency of conversion must be known.

2. END USE SHARES OF TOTAL DELIVERED ENERGY

It is assumed that air change related heating losses discussed here are accounted for solely by delivered space heating energy and not from any other energy use. (Gains from other sources are assumed to be taken into account by using a lower 'heating degree-day base temperature' than the actual indoor temperature – see Orme, 1998, for more details.) Therefore, space conditioning use (heating and cooling) is a significant quantity that should be examined. The estimated totals of the space heating and cooling energies are presented in Figure 1, which relies on hot water and space cooling use published in HPC (1994). The space heating data were either taken from published sources, or estimates were made for each country using the total delivered energy use as a guiding upper limit. The data for the remaining uses (i.e. cooking, lighting and appliances) were deduced from the difference between the total use, and the sum of space conditioning and hot water use.

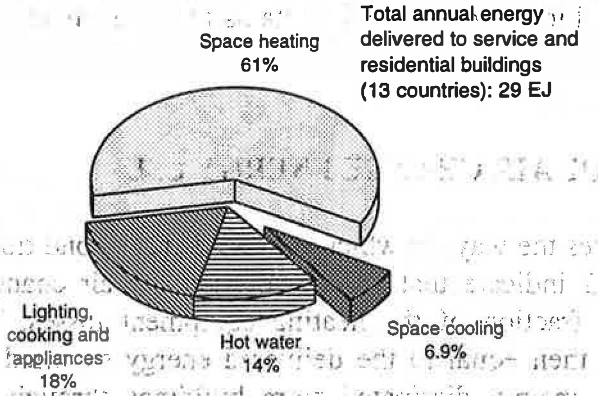


Figure 1: End use shares of delivered energy use in the service and residential sectors

3. DATA AND METHODS REQUIRED TO ESTIMATE AIR CHANGE ENERGY

Key data for a basic estimate of the air change energy use are the number of buildings and the average conditioned (heated or cooled) volume, shown in Table 1. Also, it is essential to know average air change rates and the required outdoor to indoor specific air enthalpy changes. The product of the internal volume with the air change rate will give the volume flow rate of air to be conditioned. Conversion from area to volume for the service sector was achieved by multiplying the area (column 4 of Table 1) by an assumed room height of 4 m.

TABLE 1

Background data for the service and residential sectors in the 13 countries

Country	Population $[10^6]$ (1994)	Heating degree-days [K·d]	Total service sector heated floor area $[10^6 m^2]$	Number of dwellings $[10^6]$	Mean dwelling volume $[m^3]$
Belgium	10.1	2300	140	3.90	351
Canada	29.3	4300	500	9.60	340
Denmark	5.21	2900	89	2.00	259
Finland	5.09	(5000)	84	2.30	234
France	57.9	(2450)	690	22.0	231
Germany	81.4	3600	1100	34.0	225
Netherlands	15.4	2800	110	6.00	250
New Zealand	3.53	1700	45	1.19	223
Norway	4.34	(3800)	87	1.75	266
Sweden	8.78	3600	170	4.04	263
Switzerland	6.99	3000	120	3.16	234
UK	58.4	(2500)	520	24.1	210
USA	261	(2700)	4700 (cooled 3500)	96.6	337

For the service sector in BE, DK, FR, NL, UK and USA, the specific enthalpy change calculations were based on Colliver (1995). Separate calculations were performed for heating and cooling in the USA, for which a population-weighted average of the specific enthalpy changes was taken. Heating and cooling (including dehumidification) enthalpy changes were also converted to delivered energy use separately. For the other countries the basis was heating degree-days (see Orme, 1998). Assumed residential sector delivered energy conversion efficiencies were also applied to the service sector (shown in Column 5 of Table 2). The average air change rate in service sector buildings was assumed to equal 0.75 h^{-1}. A check '✓' in column 2 of Table 2 indicates that the heating degree-day method was used to estimate the residential sector air change energy, for which appropriate data can be found in Tables 1 and 2. In particular, Column 3 of Table 2 contains assumed (mainly estimated) values for the air change rate.

4. ESTIMATES OF AIR CHANGE ENERGY USE

Figure 2 summarises the ways in which delivered space conditioning energy is dissipated. The arrows in Figure 2 indicate that both of the heating air change and conduction losses are associated with a fraction of the heating equipment losses. Their sum together with the equipment loss is then equal to the delivered energy supplied for heating. Delivered space cooling energy is mainly dissipated from buildings through the exhausts of air cooling equipment. Considering the building stock of the 13 countries collectively, the total annual loss of delivered heating energy due to air change is estimated to amount to 9.3 EJ, which is 48% of delivered space conditioning energy (including heating equipment losses). Alternatively stated, it is 53% of delivered space heating energy alone.

TABLE 2

Methods used for estimating the residential sector air change energy

	Heating degree-days and average air change rate	Assumed air change rate [h^{-1}]	Other source	Assumed residential sector average equipment efficiency
Belgium	✓	0.75	AIVC (1994)	0.60
Canada	✓	0.4	Swinton (1995)	0.75
Denmark	✓	0.5		0.75
Finland			AIVC (1994)	0.69
France		0.5	Lemaire (1995)	0.75
Germany	✓	0.5	AIVC (1994)	0.78
Netherlands	✓	0.5	AIVC (1994)	0.70
New Zealand	✓	0.5		0.75
Norway			AIVC (1994)	0.90
Sweden	✓	0.4 (a)	AIVC (1994)	0.90
Switzerland	✓	0.7	AIVC (1994)	0.75
UK			Shorrock et al (1992)	0.65
USA			Sherman and Matson (1996) (b)	0.80

Notes: (a) Average air change rate based on a measurement survey. (b) Estimate based on modelling representative sample of different dwelling types.

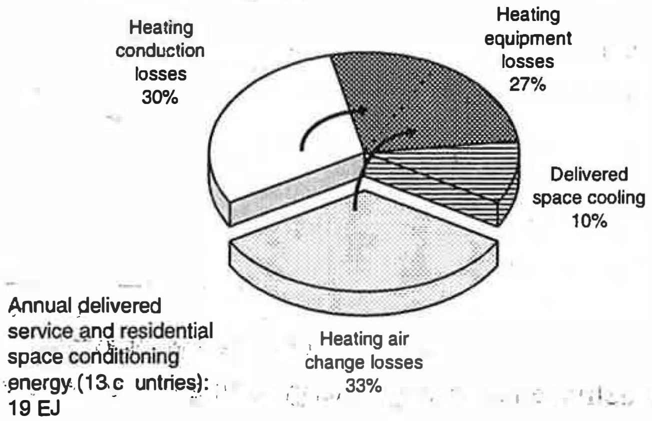
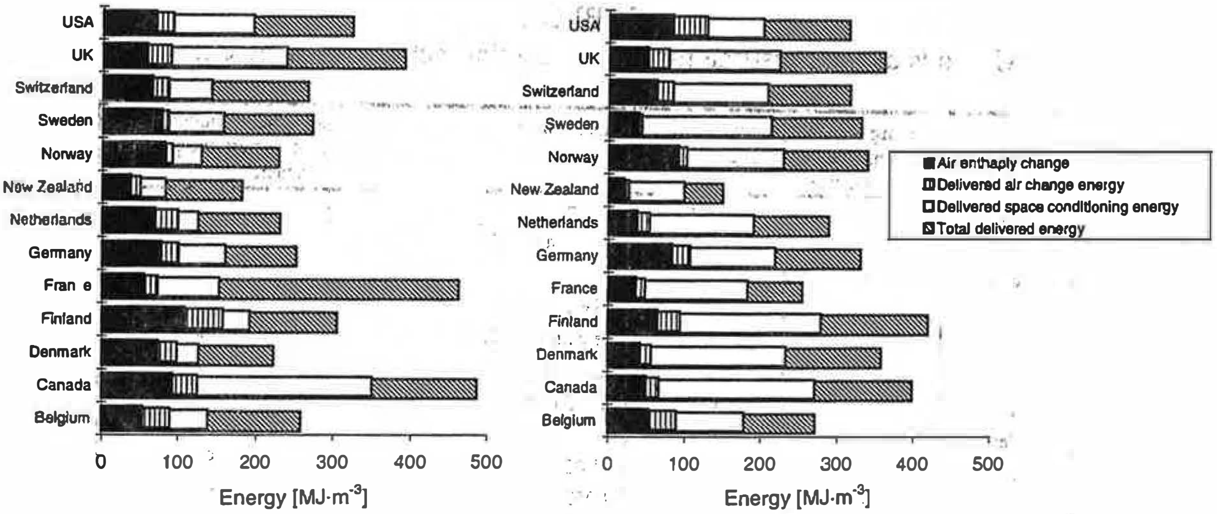


Figure 2: Dissipation of space conditioning energy in the service and residential sectors

The space conditioning energy shown in Figure 3(a) includes delivered heating and cooling energy for D, UK and USA, while for Figure 3(b) the value for USA includes heating and cooling also. For all other countries in these Figures, it indicates heating alone. For the service sector, the space conditioning values presented are only rough estimates for BE, CA, DK, NL, NZ, and NO, while the same also applies for the residential sector in BE, D, NL, NZ, and CH. Normalised service sector energy use is shown for each country in Figure 3(a). The air enthalpy changes illustrated in this Figure are purely climate dependent, because the same air change rate (0.75 h^{-1}) was assumed for all countries. For BE, CA, NL, NZ, and CH both the service sector space conditioning energy use and the total sector volume were estimated, so their normalised conditioning energy values are only very approximate. It is apparent from Figure 3(b), which shows residential energy use per unit volume, that with the exception of NZ, there are few similarities between the residential sector and the service sector of any country. The normalised air enthalpy changes are observed to be very similar for most countries, except for NO, D and the USA, which are close together at a larger value. If the outdoor air supply rate per occupant were to be universally reduced to a minimum level, taking into account metabolic needs and pollutant loads, then it is conceivable that the heating air change energy loss could be reduced to approximately a third of the current level. This is indicated in Figure 4.



(a) Service sector *(b) Residential sector*

Figure 3: Annual delivered energy use per unit building volume

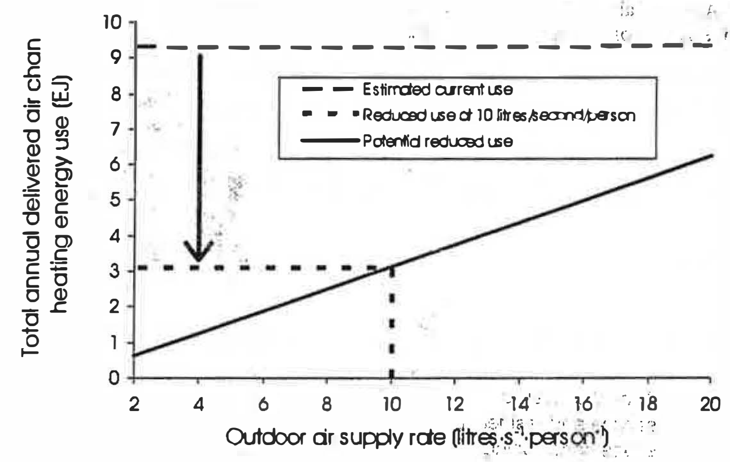
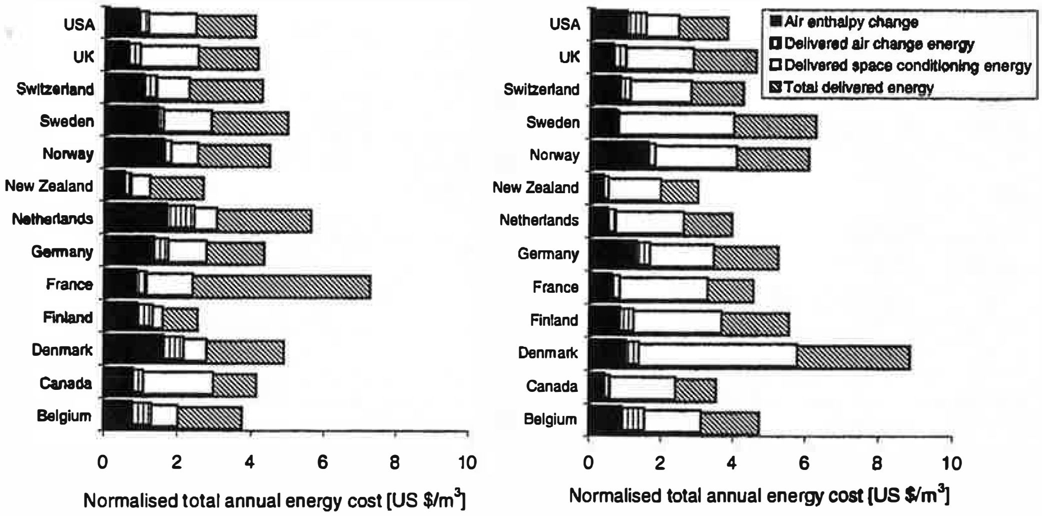


Figure 4: Potential delivered air change energy saving for the service and residential sectors

5. FINANCIAL EXPENDITURE DUE TO AIR CHANGE ENERGY USE

Figure 5(a) shows the normalised (by conditioned building volume) estimated financial expenditure by the service sector for each country, whilst similarly, Figure 5(b) shows the residential sector. The calculation of the annual cost of delivered air change energy relies on the further assumption that the proportion of each energy source (oil, gas, electricity, etc) used for space conditioning is identical to that for the aggregate of all end uses. Energy source data are 1994 values from IEA (1996). Residential energy prices were obtained directly from IEA (1997), generally for 1996 or 1997, except for electricity prices in CA, which were from 1994. Also, gas prices for SE are missing for the residential sector. Most service sector prices were from 1992, except for electricity prices, which were estimated by taking the average of industrial and residential prices (IEA, 1997) for each country. Certain other service sector prices were also found by taking the average of industrial and residential prices from IEA (1997). The discrepancy between the sum of oil, gas, electricity, and district heat with total energy use (because coal and renewable sources are not considered in the financial study) is less than 5% for service sector energy use and less than 15% for the residential sector, except FR, for which it is 35%. This is because data are missing for residential prices for renewable sources in France, which contribute a significant amount of energy. The residential price for 'district heat' is assumed to equal the price for oil plus 10% for all countries and the residential oil price for NZ is assumed to equal the industrial price plus 50%.



(a) Service sector *(b) Residential sector*

Figure 5: Annual energy expenditure per unit building volume

In summary, for all 13 countries, the totals for the service sector are: air enthalpy change 32 billion US$; delivered air change energy 42 billion US$; delivered space conditioning energy 85 billion US$; total delivered energy 150 billion US$. For the residential sector they are: air enthalpy change 56 billion US$; delivered air change energy 82 billion US$; delivered space conditioning energy 170 billion US$; total delivered energy 260 billion US$.

6. CONCLUSIONS

In this paper, estimates have been presented quantifying the energy impact of air change on total energy use in service and residential sector buildings for 13 industrialised countries. This involved a basic analysis of currently available data sources, together with the estimation of essential 'missing' data. Delivered air change heating energy losses were then found to total 9.3 EJ, for these countries collectively, which represents 53% of current estimated delivered space heating energy. Potentially this may be substantially reduced, by providing adequate fresh air on the basis of metabolic needs and pollutant loads. Although many data still remain to be satisfactorily identified, it is evident that the results highlight that air change related energy losses are as important as conduction and equipment losses in dissipating delivered space conditioning energy from buildings. In fact, as national standards, regulations or codes of practice improve the thermal integrity of buildings and increase equipment efficiency, it is expected that ventilation and air movement will become the dominant loss mechanism.

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