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Estimating the Energy Impact of Ventilation and Infiltration in AIVC Member Countries

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Introduction

It has been estimated in the Energy Conservation in Buildings and Community Systems Strategy Plan (IEA, 1994c) that about one quarter of all energy is consumed in dwellings within the countries of the Organisation for Economic Co-operation and Development. Also, in dwellings, within the Air Infiltration and Ventilation Centre's member countries, the energy used for space heating and cooling accounts for between 60% - 70% of the total energy consumed. Furthermore, it is predicted (IEA, 1994c) that ventilation and air movement is expected to become the dominant heat and cooling loss mechanism in buildings of the next century.

As part of its programme of work, the AIVC has co-ordinated attempts to quantify the part of delivered energy that is specifically associated with infiltration and ventilation of buildings. This has been achieved by means of a workshop, a survey and a conference. The purpose of this paper is to present estimates of the current situation for dwellings. The calculations given here have been performed for each of the member countries. This article expresses the energy impact in terms of both delivered energy and the consequent carbon dioxide production. For some countries the air change-related energy data have been found from published sources, and in other cases, a nominated representative from a particular country has estimated the situation, or has approved such an estimation.

Definitions

Primary energy is defined to be the sum of energy consumed directly by end-users (*delivered or final energy*) and the energy lost in the production and delivery of energy products (see Schipper and Meyers, 1992). As an approximate guide, total final consumption (TFC) is about 70% of the total primary energy supply (TPES), with the other 30% lost in the production and transmission of final energy. Exact values depend on how individual countries generate electricity and heat.

For the purpose of this discussion, the energy content of the air flowing through a building will be referred to as the air enthalpy. There can be up to two purely building-related components contributing to the overall air change rate:

(i)ventilation provided intentionally by means of a purpose-designed system, and

(ii)background infiltration through cracks and gaps in the building structure.

Also, there may be a significant contribution to the air change rate from occupant-related airing, such as window and door opening. For heating scenarios, an evaluation of the energy lost from buildings is based on heat transported by the outgoing air stream. In the case of cooling, the basis is the energy that must be extracted from the supply air in order to lower its temperature and humidity to their cooling set points. These are only the starting points for considering the total energy impact of ventilation and infiltration from an economic point of view. More important quantities are the total primary and delivered energies (defined above) that have been expended in order to suitably prepare the incoming air.

Methods of calculating the energy impact and associated CO_2 production

Various methods have been used in the studies of the countries to estimate air change-related energy consumption. A brief indication of the method selected for each country is shown in Table 1. More details can be found in the following sub-sections.

Estimates of Internal to External Temperature Difference with Heating Degree-Days

For countries denoted by an X in column 2 of Table 1, it was considered acceptable to use the heating degree-day method, mainly due to currently low levels of dehumidification and cooling. Average values for the whole countries are given in column 3 of Table 2, in which values that were not used in this study have been

Country	Heating degree days and average air change rate	Published source for average air change rates determined by measurement survey	Modelling representative sample of dwelling types	Other source
Belgium	X			Wouters, 1994
Canada	X			
Denmark	X	Bergsøe, 1993 and 1994		
Finland		Ruotsalainen et al, 1992		Heikkinen, 1994
France				Lemaire, 1995
Germany	X			Steimle, 1994
Netherlands	X			de Gids, 1994
New Zealand	X			
Norway				Brunsell, 1994
Sweden	X	Norlén et al, 1993		Kronvall, 1994
Switzerland	X			Dorer, 1994
UK				Shorrock et al, 1992
USA			Sherman et al, 1993	

Table 1 Methods used for estimating the air change energy

placed in parentheses.

However, it includes an implicit assumption that all dwellings in a region are heated to precisely the base temperature (excluding incidental gains) throughout the entire heating season.

Using the degree day method, greater precision may be achieved by dividing a country into distinct regions and treating them on an individual basis. In this way regional variations in factors such as airtightness and degree-days may be taken into account. For example, the total ventilation energy for Switzerland was found in this way.

Country	Population $/10^6$	Heating degree-days, / K.d	Number of dwellings, $/ 10^6$	Mean dwelling volume, $/m^3$
Belgium	10.0	2300	3.90	351
Canada	27.4	4300	9.60	340
Denmark	5.17	2900	2.00	259
Finland	5.04	(5000)	2.30	287
France	57.4	(2450)	22.0	231
Germany	80.6	3600	34.0	225
Netherlands	15.2	2800	6.00	250
New Zealand	3.41	1700	1.19	223
Norway	4.29	(3800)	1.75	266
Sweden	8.68	3600	4.04	263
Switzerland	6.91	3000	3.16	234
UK	57.9	(2500)	24.1	210
USA	255	(2700)	98.4	337

Table 2 Background data for the countries

Air Change Rates

Modelling

Heating degree days alone do not provide an adequate indication of the likely space conditioning consumption in countries such as the USA, where there is a significant amount of cooling liability. Therefore, a more sophisticated method is needed. The approach taken by Sherman and Matson (1993) was to consider the US dwelling stock in terms of a limited number of (but representative) building types, and to apply a simplified infiltration model to each of these. Estimates of the distribution of air change rates and the consequent air change energy consumed can then be made with knowledge of the likely airtightness of each of these types, and their distribution across the country.

Measurement surveys

Another approach to determining average air change rates is to undertake large scale measurement surveys. An example of this type of approach is illustrated by Norlén and Andersson (1993), who describe such a survey of approximately 1200 Swedish dwellings. The results were used by Kronvall (1994) to estimate the energy consumption related to air change in Sweden.

Carbon dioxide production due to ventilation and infiltration energy consumption

The carbon dioxide (CO_2) emissions resulting from energy use in the residential sector were estimated from the total annual CO_2 production from energy-related sources for each country (IEA, 1994a). This involved taking the sum of the CO_2 produced due to electricity consumption and that from fossil fuel TFC by the sector. These were derived by weighting the fossil fuels consumed for electricity production against the fossil fuel energy consumed directly, taking into account transformation and production losses.

Results of the study

The majority of the total delivered energy (total final consumption, TFC) data were derived from energy balances published by the International Energy Agency (IEA, 1994b). Figure 1 shows the data for the residential sector. The year selected for this study was 1992, being the most recent one for which data was available. An exception to this was France, information about which was received from Lemaire (1995). The TFC data normalised per dwelling, as indicated in Figure 2, were found by dividing the total energy by the number of dwellings in each country.

The space conditioning energy data given in Figure 1 were found by taking estimated fractions of the total delivered energy to the residential sector. The space conditioning values in Figure 2 were derived in the same way as in Figure 1, except that they were also normalised per dwelling.

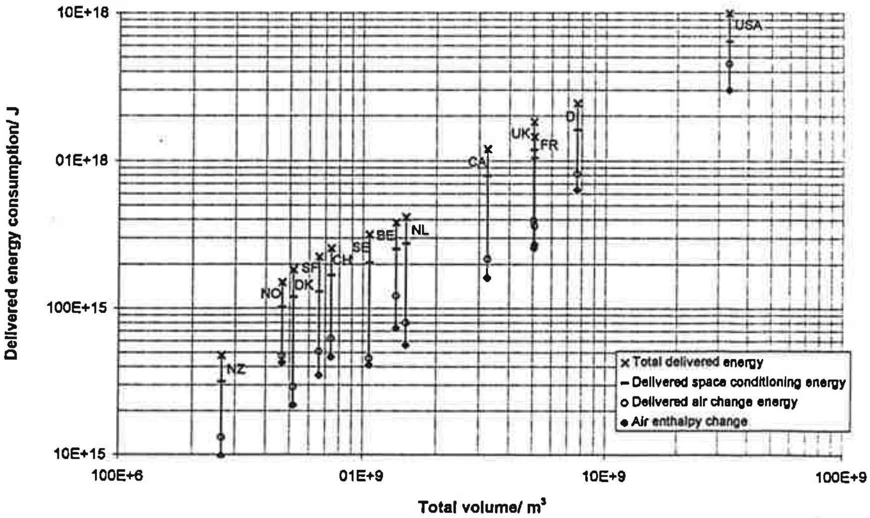

Figure 1: Residential sector - annual delivered energy consumption in relation to total sector building volume

It can be seen in Figure 1 that total estimated delivered energy to the residential sector in each country is in proportion to the total internal volume of dwellings. It should be stressed that both axes in Figure 1 have logarithmic scales. There are differences in the ratios between components of the total delivered energy, which is evident from the differing lengths of the lines joining the components. The air change energy data also seem to be in proportion to the total internal volume, although the trend is less pronounced than for the total delivered energy.

In Figure 2, the energy data are normalised to express average values per dwelling. The most prominent feature of Figure 2, which shows the energy used per dwelling, is the wide variation in energy consumed by an average dwelling in each country. This can partially be explained by the differing climatic circumstances of each country. The total delivered energy and the estimates of the space conditioning load are linked, as are the delivered air change energy and the air enthalpy change. But, these two pairs were derived independently. It is therefore interesting that variations in the first of these pairs between countries are generally reflected by the second pair.

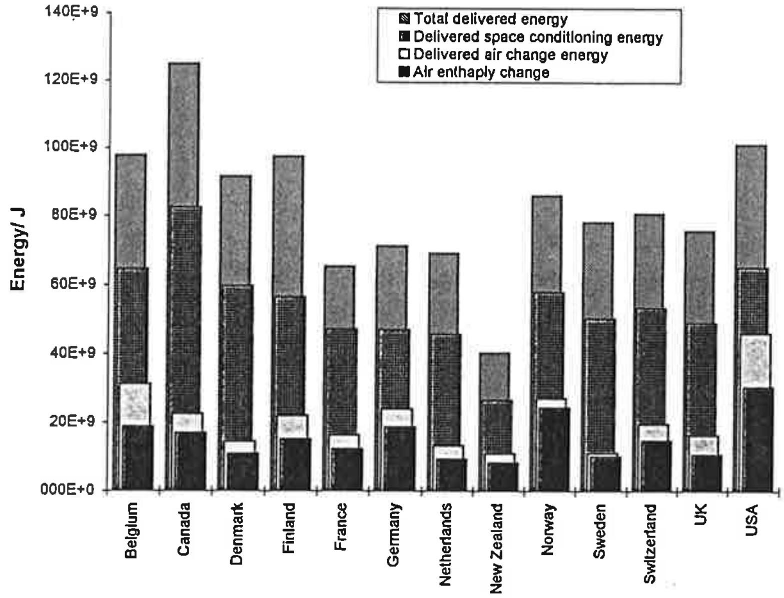

Figure 2: Residential sector - annual delivered energy consumption per dwelling

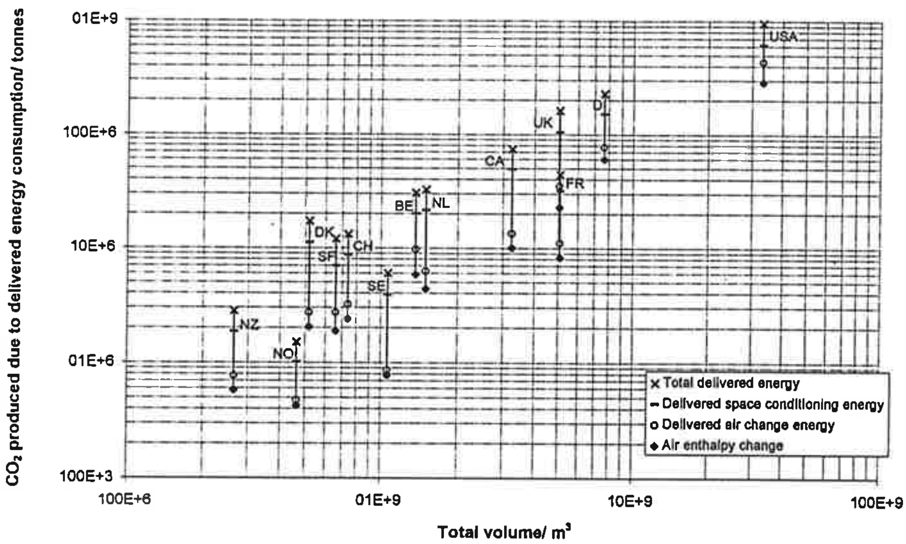

Figure 3: Residential sector - annual CO_2 production in relation to total sector building volume

Figure 3 shows the estimated CO_2 emissions due to each component of residential energy consumption. Again, both horizontal and vertical scales are logarithmic. Emissions for countries which rely more on non-CO_2 producing for example Norway and Sweden) are, of course, seen to produce less CO_2 in relation to their energy consumption than other countries.

Conclusions

The general result that emerges from this study is that the data collated and deduced for the residential sector seem to be self-consistent. This was certainly not obvious at the onset, especially since many of them originate from independent sources. In particular, the air change rate data are only approximate, resulting in an important potential source of error.

Qualitatively, there appears to be a good correlation between the total internal dwelling volume for each country and the total delivered energy for the sector. But, the correlation between volume and air change energy (both delivered and air enthalpy change) is not quite so strong. This may be partially explained, perhaps, by the differing conditioning needs on account of climatic circumstances.

Although the air change energy data given in the above Figures are represented by single values, they are in reality much less well-defined. Even with complete knowledge of the airtightness of building stock, the air change rate is still heavily influenced by other factors such as the weather (which varies from year to year) and occupant behaviour. A more in-depth analysis would be needed to determine the uncertainties of the energy values, and only then could the realistic potential for any air change energy reduction be quantified. However, it is anticipated that the calculated energy and CO_2 data presented at least 'orders of magnitude' with which to compare more detailed studies.

Acknowledgements

Some of the results presented here are based on the contents of a workshop (March 1994) and survey (February 1992) conducted by the AIVC. The AIVC would like to gratefully acknowledge the contributions of those who participated in the above. In addition, the members of its Steering Group have provided valuable support and co-operation by reviewing the analyses concerning their national situations for energy consumption in the residential building sector.

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Energy Requirements for Conditioning of Ventilating Air

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1. Introduction

Outdoor air is brought into buildings for many different reasons such as free cooling, "fresh air" and pollution reduction. Over the last several years structures have been built tighter to reduce air infiltration and conserve energy used to heat the air coming into the building. Several standards and organisations have been specifying minimum amounts of "fresh" outdoor air for indoor air quality purposes. There have been several questions however about the energy impact and/or tradeoffs involved between bringing in outdoor air (for pollution reduction) and the energy required to condition this air. This work is intended to provide an initial estimate of the theoretical energy required.

2. Objectives

The objectives of this work are: first to determine the theoretical energy requirements per constant mass unit of outdoor air used for ventilation for a number of different climates and locations in North America and Europe; and secondly to determine the variation of this annual ventilation heating and cooling energy requirements due to the setpoints for temperature and humidity.

3. Psychrometric processes associated with ventilation

A psychrometric chart is a visual presentation of the possible characteristics of an air-water vapor mixture and is often used to describe the possible conditions or statepoints which may be obtained by the air. The psychrometric chart is commonly used to determine the heat and moisture changes in the air as it goes from one condition (such as 32 Deg C, 65% relative humidity outdoor air) to another condition (26 Deg C, 40% relative humidity) such as inside a building.

The psychrometric chart can also be used to determine the heat and moisture which must be added or subtracted from the air. Therefore if the average conditions of the outdoor air known, the theoretical energy which must be added or subtracted from the air to heat, cool and/or dehumidify it when the air enters the building may be determined.

The amount of sensible energy needed to heat or cool air is calculated from:

$$Sensible = (C_{pa} + W^{*}C_{pw})(t_{db\text{-}setpt} - t_{db\text{-}outside}) \qquad (1)$$

where: