Air Infiltration Review

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International Energy Agency - AIVC

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16th AIVC Conference

Implementing the Results of Ventilation Research

19th-22nd September 1995
Hyatt Grand Champions Resort, Palm Springs, California, USA

Report by Malcolm Orme, Air Infiltration and Ventilation Centre

The 16th Annual AIVC Conference, held at the Hyatt Grand Champions Hotel in Palm Springs, California, attracted 53 presentations and participants from all AIVC participating countries. Topics included energy efficient ventilation strategies, control and user interaction, measurements and the application of mathematical models. Richard Karney, Director of the Building Systems and Materials Division at the US Department of Energy, delivered the Welcome Address and introduced the Keynote Speaker, Commissioner Jananne Sharpless from the California Energy Commission, who spoke about the need for long-term public investment to complement the research and development projects funded by private industry.

Energy Impact

Several presentations focused on energy consumption. The first by Don Colliver (University of Kentucky, USA) outlined the results of a study to determine the energy necessary to condition a fixed flow rate of outside air to various heating and cooling set points. Later on, Jürgen Röben, of the University of Essen in Germany, discussed the benefit of low energy dehumidification, achieved with an open cycle liquid desiccant system, whilst Professor Fritz Steimle, also from Essen, described how the separation of sensible cooling from latent heat removal can allow a more energy efficient system.

Standards

A workshop on standardisation encouraged various speakers to give an informal presentation on the current situations in their respective countries. Codes and Standards were also the subject of several papers delivered throughout the conference and included a presentation by Gene Tucker (EPA, USA) about the

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current revisions to ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality". Also from the USA, Bud Offermann (Indoor Environmental Engineering) demonstrated the procedure for an experimental evaluation of ASHRAE Standard 129 "Standard Method of Measuring Air Change Effectiveness".

Offices and Large Enclosures

Measurements to determine ventilation effectiveness in four mechanically ventilated New Zealand office buildings highlighted the importance of planning the ventilation system around the floor layout. Continuing with offices, Peter Wouters (BBRI, Belgium) described the installation and operation of an infra-red (IR) detector controlled ventilation system. It was shown that, provided attention was paid to duct airtightness, then the IR detection facility can provide significant energy savings. Elia Sterling (T.D.Sterling & Assocs, Canada) summarised the planning and design of some prototype energy efficient offices, and Earle Perera (BRE, UK) illustrated how trickle ventilators are able to supply adequate background ventilation for occupied offices. Alois Schälin (Federal Institute of Technology, Switzerland) reported on both the method of predicting air flows through open aircraft hanger doors using transient thermal models and computational fluid dynamics (CFD) and the possibility of using huge air curtains to reduce heat loss in such structures. From Sweden, Sture Holmberg (National Institute of Occupational Health) showed encouraging results from field measurements, carried out in the plastics industry, of the principles of practical displacement ventilation. Two strategies for cooling (without dehumidification) in non-residential buildings were explained by Andrew Martin (BSRIA, UK) and Willigert Raatschen (Dornier GmbH, Germany). The UK strategy concerned the use of automatic controls for natural ventilation and passive cooling, whereas the German author presented the testing of a thermo-syphoning facade system.

Ventilation in the Home

Lars-Göran Månsson (LGM Consult AB, Sweden) discussed the various criteria influencing domestic ventilation system performance. As part of the same study, Johnny Kronvall (J & W Consulting Engineers AB, Sweden) described the simulation of passive stack ventilation (PSV) in a single family house and suggested possible improvements. From the Swedish National Testing & Research Institute, Thomas Carlsson outlined the results of calculations for mechanical exhaust and balanced mechanical systems, concluding that outdoor air should be supplied only via the bedrooms for both these systems. Also, Åke Blomsterberg, from the same organisation, contrasted the outcome of long-term monitoring of a representative sample of dwellings in Sweden for different ventilation systems and also showed the results of an occupant survey of indoor climate and user interaction in post-1988 single family Swedish dwellings. Findings reported by Duncan Hill of an occupant survey in Canada concluded that increased consumer education and refinement of controls and maintenance strategies would be needed to ensure more success with mechanical ventilation with heat recovery (MVHR).

Frank Dehli discusses the suitability of dessicant and heat recovery wheels for industrial applications

Ulf Krüger (Chalmers University, Sweden) proposed that slot inlet devices are very difficult to position without causing thermal discomfort. He justified this with studies of temperature and air velocity distributions around

Air Infiltration Review

Editor: Janet Blacknell

Air Infiltration Review has a quarterly circulation of 3,500 copies and is currently distributed to organisations in 40 countries. Short articles or correspondence of a general technical nature related to the subject of air infiltration and ventilation are welcome for possible inclusion in AIR. Articles intended for publication must be written in English and should not exceed 1,500 words in length. If you wish to contribute to AIR, please contact the Air Infiltration and Ventilation Centre. Please note that all submitted papers should use SI units.

Conclusions and opinions expressed in contributions to Air Infiltration Review represent the author(s)' own views and not necessarily those of the Air Infiltration and Ventilation Centre.

these devices in relation to occupation zones in residential buildings. Still in Scandinavia, Jørn Brunsell (Norwegian Building Research Institute) reported field tests of dynamic insulation in four houses. These revealed that it is essential for the air flow to remain constant, irrespective of climate, occupants, or infiltration.

Retrofit

Retrofit activities are very important, because the existing building stock is substantially larger in size than the new building stock. The number of buildings in need of renovation is therefore significant. Peter Op 't Veld (NOVEM bv, The Netherlands) described the E'novation programme of renovation of dwellings, in which buildings with high energy use, poor indoor air quality (IAQ) and often moisture and mould growth, were made more energy efficient (by an average of 39%) with, in addition, improved IAQ. An overview of a French guide to assist in the choice and sizing of PSV systems for apartment retrofits for ventilation and gas exhaust flues was given by Jean-Georges Villenave of CSTB. From VTT Building Technology in Finland, Jorma Sateri argued that the installation of heat recovery in existing Finnish multi-family buildings would be economically feasible if their airtightness was 2 to 3 air changes per hour at 50 Pa, or better.

Mites, Mould and Moisture

Jan Nielsen (Danish Building Research Institute, Denmark) measured humidity levels in 16 humidity-controlled mechanically ventilated apartments in conjunction with another 16 identical apartments (as a control group) with constant ventilation. Interestingly, the humidity-controlled apartments were found to use less energy for heating than the control group, but still met humidity requirements. Furthermore, Donald McIntyre (EA Technology, UK) presented survey results (conducted during a winter period) of humidity and dust mites in 20 houses with MVHR and 20 other houses, from which he concluded that the majority of the MVHR houses had humidity levels sufficiently low to reduce dust mite numbers. This contrasted with a minority of the other houses. Sarah Palin, also from EA Technology, made a comparison of the energy consumption and resultant indoor humidity levels with each of PSV, MVHR, and mechanical extract fans (MEF) in a single family test house. Nigel Oseland (BRE, UK) found that the results of a postal survey of occupants of UK dwellings with either PSV or MEF showed, in general, that those with PSV in their homes seemed to have least problems with condensation or mould.

Radon

Paul Welsh (BRE, UK) and Fan Wang (University of Sheffield, UK) have been independently examining techniques for reducing radon concentration in UK single family dwellings. Their results presented at the Conference, indicated that extract ventilation (depressurisation) of the underfloor space produced the greatest reduction in radon levels in the living area. Pirjo Korhonen (University of Kuopio, Finland) found that radon levels in various workplaces in Finland depended mainly on the type of foundation and the magnitude of depressurisation of the work space. Richard Grot (Lagus Applied Technology, USA) explained how, using SF_6 as a tracer gas in tunnels in a uranium mine, the transport of radon through the overlying soil and into the cellars of 15 different buildings above had been investigated.

Calculation Techniques

An important mechanism for implementing research results is the production of calculation methods. Iain Walker (LBNL, USA) explained his simplified procedure for the calculation of attic ventilation rates. Willem de Gids (TNO, The Netherlands) stated that TNO now has an algorithm for the calculation of building surface wind pressure coefficients, which has been designed to take into account surrounding shielding. An integrated approach to predicting building air flows by combining network models, CFD, and thermal simulation was reported by Jan Hensen (University of Strathclyde, UK) together with the 'onions' and 'ping-pong' alternative methods of coupling heat and air flow solvers. Both Muriel Regard (ENTPE, France) and Martin Simons (Coventry University, UK) presented their work on using CFD for ventilation effectiveness calculations. Prompted by ASHRAE Standard 62-1989, Milton Meckler (The Meckler Group, USA) demonstrated dynamic IAQ models of ventilation system response to emissions.

Measurement Techniques

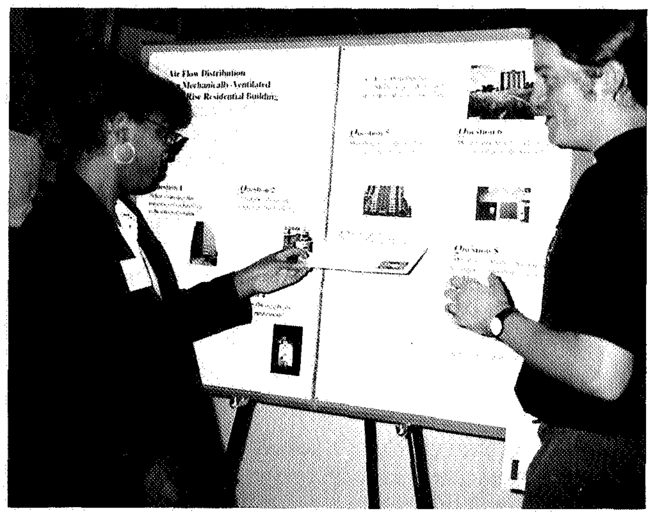
A crucial aspect of ventilation research is having good measurement techniques. Stephen Flanders (US Army Cold Regions Research and Engineering Laboratory, USA) pointed out the uncertainties associated with fan pressurisation measurement, in particular, if ISO, CGSB and ASTM protocols are followed. Michael Cui (University of Illinois at Urbana-Champaign, USA) has been using particle-imaging velocimetry to produce whole room air velocity profiles. Peter Wouters (BBRI, Belgium) proposed that acceptable results can be achieved for the investigation of airborne moisture transport if accurate humidity measurements are made and tracer gas studies are used to find air flow rates.

Conference Awards and Banquet

Miriam Byrne, Imperial College, UK received the Best Paper award for her presentation entitled "Particulate Deposition on Indoor Surfaces - its Role, with Ventilation, in Indoor Air Quality Prediction". The Best Poster was awarded to Richard Diamond and Helmut Feustel of LBNL, USA for their poster entitled "Air Flow Distribution in a Mechanically Ventilated High-Rise Residential Building". Both these awards were presented by the Guest Speaker, John Millhone, Senior Fellow, Advanced International Studies, Battelle Pacific Northwest Laboratories (on assignment from the US Department of Energy).

John Millhone presents the award for best paper to Miriam Byrne

After the awards, John Millhone delivered an address entitled "AIVC - Looking to the Next 16 Years" in which he stressed the importance of the AIVC grasping the new opportunities created by the growing international recognition of the importance of energy efficiency. He said that changes are occurring in Central and Eastern Europe, as countries in this area emerge from a centrally controlled to a free-market economy which exposes their profligate energy use and artificially low prices. He also saw AIVC playing an expanded role in the growing concern over the damage to the earth's climate being caused by greenhouse gases. He elaborated by saying that as the dominant greenhouse gas emission is carbon dioxide which is produced primarily by the burning of fossil fuels for energy, then it follows that energy efficiency programs are the fastest, cheapest and largest option available for containing this problem. He went on to say that the AIVC must expand their mission to provide information and services, designed for the air infiltration and ventilation problems of the emerging free-market countries, if necessary at a discounted cost or even funded through a third party. In this way, he sees it as a low-cost method of buying a world-class technology transfer service and the unique and significant findings of the researchers in these new participating countries would enrich the body of knowledge of the AIVC and give it an expanded relevance to major energy efficiency and environmental problems of the next 16 years. Just before the close of the Conference, the Summing-Up was given by Martin Liddament, Head of the AIVC, who reviewed how this field has progressed over the last 16 years.



Iain Walker explains the award-winning LBNL poster to Muriel Regard

The Proceedings of the 16th AIVC Conference can be obtained from the Centre priced £50.

International Energy Agency's Air Infiltration and Ventilation Centre

17th Annual AIVC Conference
Optimum Ventilation and Air Flow Control in Buildings

Hotel 11, Gothenburg, Sweden, Tuesday 17th-Friday 20th September, 1996

First Announcement and Call for Papers

Abstracts of approximately **300-500 words** are invited on the following, or related, topics and should be submitted by **February 14th, 1996.** Notification of acceptance, or rejection of the abstract will be sent at the beginning of April 1996, and the deadline for final papers will be **July 31st, 1996**.

Specific areas of interest include:
**ventilation solutions for large buildings (commercial, public, etc) * passive cooling * achieving optimum air distribution * ventilation case studies * evaluation of ventilation performance * developments in housing * systems for building retrofit * innovative technology * developments in calculation and measurement methods*
For up to date information about this conference and other AIVC activities, contact the Centre's World Wide Web "Home Page" on http://www.demon.co.uk/aivc, or see back page.

Preview
A New Publication of the
Air Infiltration and Ventilation Centre

AIVC Guide to Ventilation

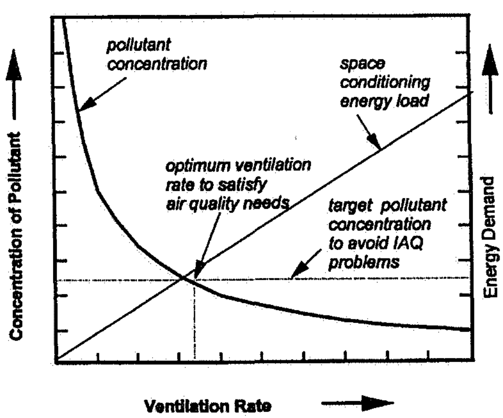
by Martin W Liddament, Head, AIVC

The purpose of the AIVC's new guide to ventilation is to review ventilation in the context of achieving energy efficiency and good indoor air quality. It is primarily concerned with providing an introduction to the topic and encapsulates the knowledge and experience derived from experts in all the participating countries of the Air Infiltration and Ventilation Centre. Numerical descriptions have been kept to a minimum, while emphasis is placed on describing ventilation and the decision making involved in selecting and planning for ventilation. By understanding this Guide, it is hoped that the reader will be able to make fundamental judgements about how much ventilation should be provided and how this should be accomplished for optimum cost and energy efficiency.

This guide is specifically aimed at the policy maker, architect, building services engineer, designer and building owners and occupiers who require a background knowledge to ventilation.

Structured in twelve chapters the first considers the role of ventilation. It looks at the need for ventilation to meet metabolic needs (oxygen and odour control), the minimum acceptable ventilation rate and at additional requirements to meet the (polluting) activities of occupants (e.g. smoking, cooking, unvented clothes drying etc.).

It is argued that too often it falls upon ventilation to accomplish tasks for which it is not intended.



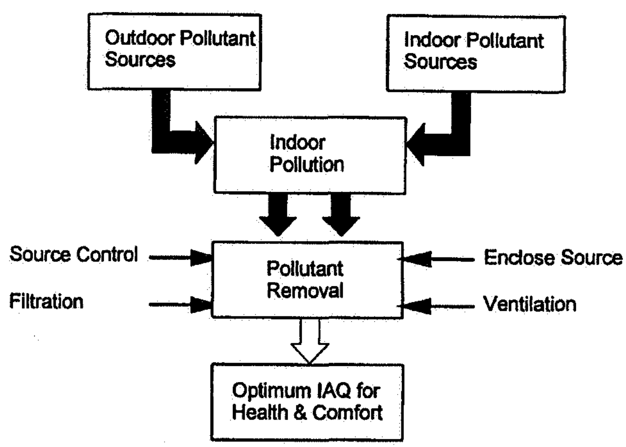
Pollutant concentration is reduced by ventilation. As the ventilation rate is increased, energy demand also grows.

Chapter 2 reviews indoor air quality. Good indoor air quality may be defined as air which is free of pollutants that cause irritation, discomfort or ill health to occupants. Thermal conditions and relative humidity also influence comfort and health. A poor indoor environment can manifest itself as a 'sick' building in which some occupants experience mild illness symptoms during periods of occupancy. More serious pollutant problems may result in long term and permanent ill-health effects. Since much time is spent inside buildings, considerable effort has focused on methods to achieve an optimum indoor environment, with particular emphasis on health, odour control, thermal comfort and energy efficiency.

Aspects of Indoor Air Quality are discussed with particular emphasis on providing an overview of indoor air quality in relation to:

- Sources of Pollutant
- Metabolism and Health
- Odour
- Sick buildings
- Comfort
- Reducing Pollutant Concentration

Above all a coordinated approach is needed to secure good IAQ as outlined in the figure below:



Securing good indoor air quality

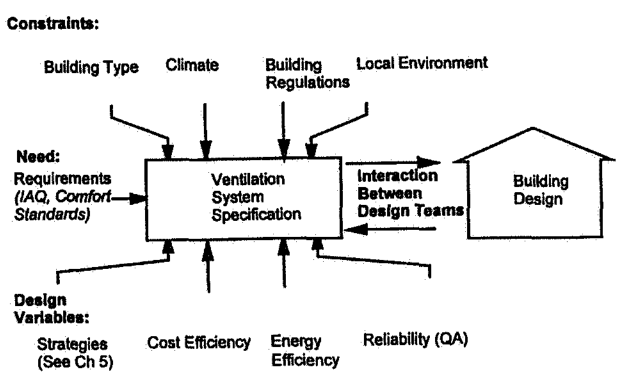
Aspects of energy impact are outlined in Chapter 3.

A considerable proportion of the energy consumed in buildings is lost by ventilation and air infiltration. This has important implications both at the consumer level, where the cost must normally be met, and at the strategic level, where it contributes to primary energy need and environmental pollution. Since ventilation is so closely linked to concern about indoor air quality, there is the further problem of identifying how much ventilation is needed to provide for a healthy indoor environment.

Since it is difficult to assess the energy impact of ventilation, the context of air change in relation to energy use is often undefined. As a consequence, no adequate datum exists from which strategic planning for improving the energy efficiency of ventilation can be developed. This difficulty stems from the enormous complexity of the task, which needs to accommodate wide variations in factors such as climate, building air tightness, occupancy patterns and approaches to ventilation. Efforts to overcome these difficulties are progressing and an attempt is made in Chapter 3 to outline the results of present progress.

Chapter 4 focuses on ventilation design criteria. A ventilation system must be designed to satisfy the required demand. In meeting this need it is necessary to consider a wide range of criteria, varying from meeting the needs of Building Regulations to planning for maintenance and replacement (Figure 2). It is also necessary to integrate the ventilation system itself into the overall design of the building, especially in relation to air tightness, room partitioning and accessibility.

Since such a wide range of parameters is involved, there is rarely a unique solution to a particular ventilation design. Instead the designer must base a judgement on the individual needs of each building. Ultimately a robust solution is needed which ensures the health and comfort of occupants. Ventilation needs must be based on criteria that can be established at the design stage of a building. To return afterwards in an attempt to mitigate problems as they arise may lead to considerable expense and failure.



Design Criteria are subjected to many parameters

Strategies for ventilation are reviewed in Chapter 5.

A wide range of systems and techniques is available to meet the needs of ventilation with each having its own set of advantages, disadvantages and applications. Sometimes choice is dictated by local climate conditions or building type. Frequently, price competitiveness and an unwillingness to deviate from the minimum specification of relevant Building Regulations or Codes of Practice can further restrict choice and also limit the opportunity for innovation. To justify a complex strategy, it is usually necessary to demonstrate advantages in terms of improved indoor climate, reduced energy demand and acceptable 'payback' periods. Strategies reviewed cover both natural and mechanical systems.

Chapter 6 looks at the potential for ventilation heat recovery. Considerable energy is lost from a building through the departing air stream. When air change is dominated by infiltration, little can be done to re-capture this energy. On the other hand, if exhaust air is centrally collected, a variety of methods for recovering or recycling the waste heat become possible. In view of the scale of ventilation energy loss, considerable effort has been devoted to the design and development of ventilation air heat recovery systems.

While the heat recovery process can be shown to be extremely efficient, benefits must always be equated against the (primary) energy needed to drive the process and capital and maintenance costs. Various hidden losses such as air infiltration must also be thoroughly understood.

Ventilation and cooling is reviewed in Chapter 7. Cooling is needed when the indoor environment becomes excessively hot or humid. This may occur as a result of high outdoor temperatures or as a consequence of excessive solar or internal heat gains. High internal gain is particularly a problem in large non-domestic buildings.

When the need for cooling is dictated by internal heat gains rather than outside temperature and humidity, much can be accomplished to reduce the need for or eliminate altogether active cooling systems. Solutions depend on climate but include cooling by ventilation (passive cooling), designing for reduced solar gains, the use of thermal mass and restricting internal heat loads.

The role of filtration to clean ventilation air is explored in Chapter 8. Filtration is a method by which particulates and, sometimes, gaseous pollutants may be removed from the air. Pollutants are intercepted by a filter while allowing clean air to pass through. This method of air cleaning is especially necessary when high concentrations of particulates are present or when the source of pollutant is derived from outside the building. Potential benefits can include improved air quality, reduced dependence on ventilation and improved energy efficiency. Filtration is not a substitute for the ventilation needed to meet the metabolic requirements of occupants.

Ventilation Efficiency and the process of air mixing is outlined in Chapter 9. Indices of ventilation efficiency characterise the mixing behaviour of air and the distribution of pollutant within a space. These two aspects may be subdivided into indices of air change efficiency and pollutant removal effectiveness respectively. Ventilation efficiency is based on an evaluation of the 'age', of air and on the concentration distribution of pollutant within the air. Some indices are based on room averaged values, while others refer to specific points or locations. This has important consequences because while room values provide some guidance to the overall performance of a ventilation system, point values indicate regions where localised poor ventilation might occur.

Chapter 10 looks at maintenance issues. Maintenance is needed to ensure the reliability of the ventilation system and to secure the economic operation of the ventilation plant. Evidence suggests, however, that maintenance is often inadequate and that the need for maintenance may even be ignored in the course of building design. Typical problems include worn gaskets, dirty fans and grilles, and ill-fitting and clogged filters. This concern has resulted in much more specific guidelines being developed for the maintenance of ventilation systems, some of which are discussed in Chapter 10. Only by correct functioning can a ventilation system be relied upon to meet the indoor air quality needs of a building.

Measurement methods are reviewed in Chapter 11. Measurements are needed to verify the performance of ventilation systems and to test the integrity of the building shell. They are essential for commissioning, diagnostic analysis, design evaluation and research. In addition, measurement results provide the fundamental means for understanding the mechanics of ventilation and air flow in buildings. Measurement data are also needed to provide background information for parametric studies on building air leakage characteristics, indoor air quality and ventilation system performance. Many measurement techniques have been developed with each having a specific purpose. An analysis of principal measurement techniques and applications is presented.

Finally, Chapter 12 reviews recent developments in calculation techniques. Calculation techniques and numerical models are essential for any design process. They provide the means by which the designer can develop and investigate an idea before being committed to the final product.

Typical design aspects cover system sizing, performance evaluation, indoor air quality prediction, energy impact assessment, and cost benefit analysis. A calculation technique or model is used to analyse the interaction of design options with fixed constraints. Such a process is necessarily iterative, with adjustments made to parameters over which control is possible, until an optimum design solution is achieved.

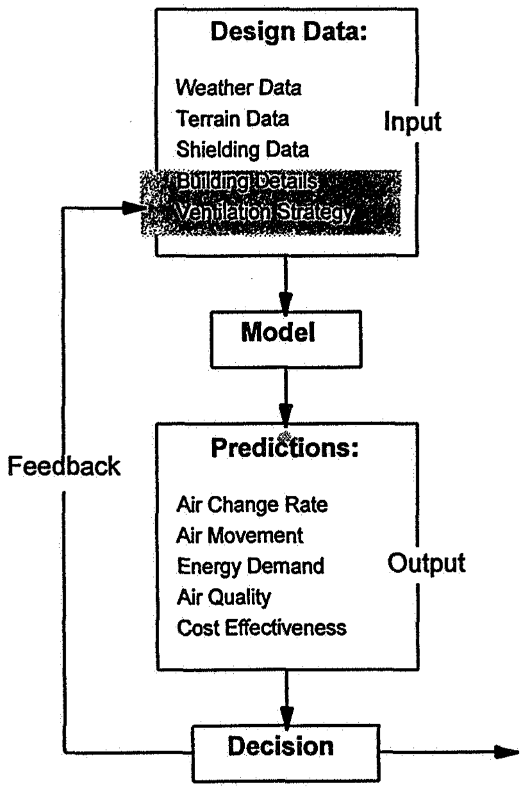
A wide range of methods of varying complexity have been developed with no single method being universally appropriate. Selection varies according to the required level of accuracy, the availability of data and the type of building under investigation.

As designs have become more complex and performance tolerances more demanding, it is increasingly important for the designer to be able to understand and use calculation techniques. This need has resulted in the development of improved algorithms and wider availability of design data.

Techniques cover methods to determine:

- air change rates in buildings and rooms.
- the flow rate of air through infiltration and purpose provided flow openings (network methods).
- air flow pattern in a space (computational fluid dynamics).

Subsidiary calculations cover pollutant transport, energy analysis and the evaluation of driving forces (wind and stack effect).



Calculation techniques are used for design and decision making

A series of appendices provide numerical support to Chapter 12 including data and a simple ventilation calculation algorithm.

The AIVC Guide to Ventilation is soon to be available from the AIVC, please send enquiries to the address listed on the back page.

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

by Malcolm Orme, Air Infiltration and Ventilation Centre

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.

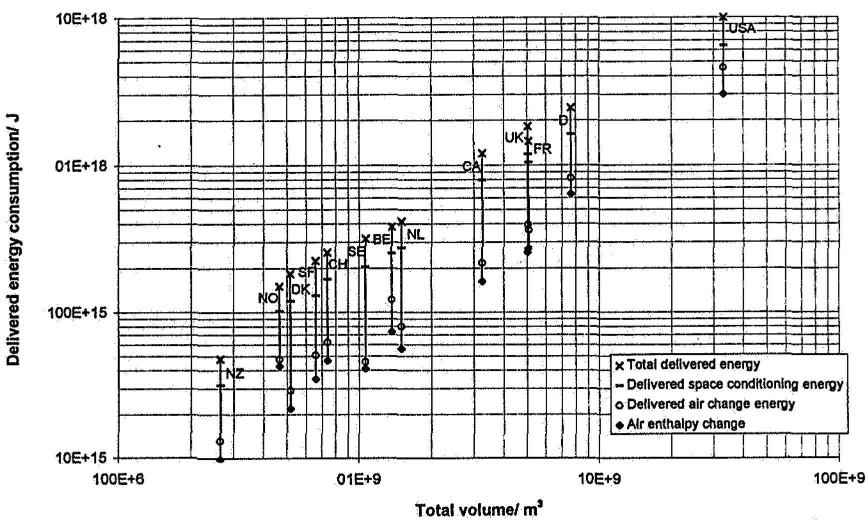


Figure 1: Residential sector - annual delivered energy consumption in relation to total sector building volume

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.

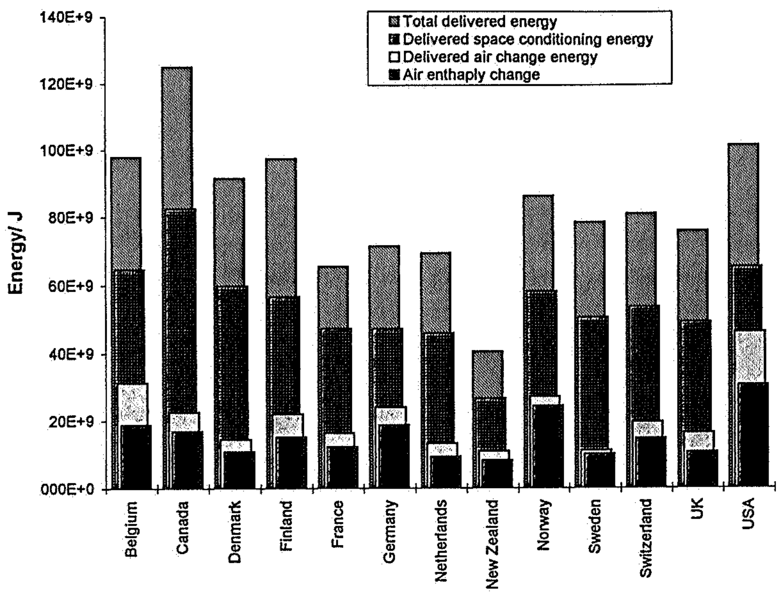


Figure 2: Residential sector - annual delivered energy consumption per dwelling

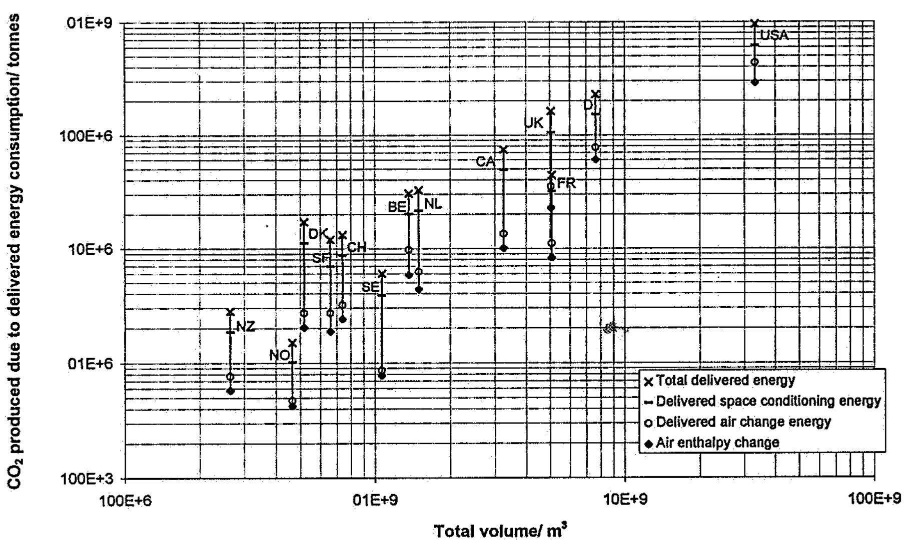


Figure 3: Residential sector - annual CO_2 production in relation to total sector building volume

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:

C_{pa} = Specific heat of dry air (1.0056 kJ/kg-dry air. Deg C)

W = Amount of moisture in the air (kg)

C_{pw} = Specific heat of water vapour (1.86 kJ/kg water. Deg C)

$t_{db\text{-}setpt}$ = Setpoint dry-bulb temperature (Deg C)

$t_{db\text{-}outside}$ = Outside dry-bulb temperature (Deg C)

Latent heat is that energy which must be added or withdrawn when water is vaporised (in the case of humidification) or condensed (in the case of dehumidification) from the air. The latent heat transfer, or the energy which must be used for moisture control with humidification/dehumidification, can be determined from the amount of moisture which must be added or removed as:

$$Latent = L * \Delta W \qquad (2)$$

where:

L = Latent heat of vaporisation (2501.3 kJ/kg water)

The amount of water which must be subtracted from the air is:

$$\Delta W = H_{setpt} - H_{outside} \qquad (3)$$

where:

H_{setpt} = Humidity ratio of the air at the setpoint (kg water vapour/kg dry air)

$H_{outside}$ = Humidity ratio of the outside air (kg water vapour/kg dry air)

If two independent measurements (such as dry-bulb and relative humidity) and the air pressure are known, the other characteristics (such as humidity ratio, wet-bulb temperature, dew-point temperature, etc) may be determined from the psychrometric chart or from equations which mathematically describe it. The computerised psychrometric routines used in this work [5, 9] are available via anonymous ftp in the directory /pub/bae/psych at the site: ftp.ca.uky.edu.

The psychrometric chart may be divided into several regions where the air being described by that region undergoes the same psychrometric process to reach the desired condition of temperature and moisture content. If the average condition (over all the hours the air is within that region) for the air within that region is known, then the energy and moisture which must be added or subtracted may then be determined. The conditions of the outdoor air fall into six different regions on the chart with respect to the desired condition of the air in the building (see Figure 1).

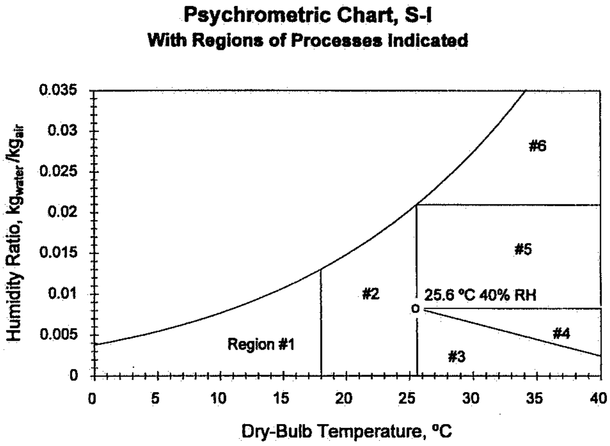

Figure 1: Psychrometric chart with regions of processes used to reach desired statepoint.

Region 1: Outdoor dry-bulb temperature less than heating setpoint

($T_{db\text{-}outdoor} < T_{dbh\text{-}setpt}$)
(Heating Region)

This is the typical wintertime condition when heat is being added to the ventilation air. In this case only sensible heat is added to the air to reach the desired statepoint since typically moisture is not controlled in heating situations. There is no intentional latent heat exchange in this region.

Region 2: Outdoor dry-bulb temperature greater than heating setpoint but less than cooling setpoint

($T_{dbh\text{-}setpt} < T_{db\text{-}outdoor} < T_{dbc\text{-}setpt}$)
(No Heating or Cooling Region)

This is the condition when the outdoor air does not need to be either heated or cooled. It represents the moderate weather conditions typically encountered during the spring and fall or at other times when neither heating or cooling are needed. This also represents the situation when the outdoor air is being introduced into the building for natural ventilation. In this case there is no sensible or latent energy exchange required to condition the air.

Region 3: Dry-bulb temperature greater than cooling setpoint temperature and wet-bulb less than desired wet-bulb

($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} < T_{wbc\text{-}setpt}$) (Evaporative Cooling Region)

The air in this region has a higher dry-bulb temperature than desired, however the outdoor wet-bulb temperature is less than the wet-bulb of the design setpoint. This condition is typically associated with hot, dry weather. Evaporative cooling (a process which approximately follows the wet-bulb line) can be used in this psychrometric region to provide the desired reduction in dry-bulb temperature. The sensible energy used to cool the air comes from the latent heat of evaporization of the water added to the air. Since there is an exchange of sensible and latent heat in this region and in practice the energy required is for pumping/spraying which has comparatively small energy expenditure, the sensible and latent energy requirements for this region will not be included in the total energy requirements.

Region 4: Outdoor dry-bulb and wet-bulb temperatures greater than cooling setpoint temperatures, dew-point less than setpoint

($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $T_{dp\text{-}outdoor} < T_{dpc\text{-}setpt}$)
(Refrigerative and Evaporative Cooling Region)

Air in this region may be partially cooled with evaporate cooling (up to the dew-point of the setpoint) and then external energy must be used to remove the remaining sensible heat if moisture conditioning is achieved. In many cases, cooling is only controlled based upon dry-bulb temperature and moisture is controlled with the system design. For the purposes of this study, the total energy required is the net of the sensible and latent heats.

Region 5: Outdoor dry-bulb temperature greater than cooling setpoint temperature, outdoor dew-point greater than setpoint and less than saturation

$T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $T_{dpc\text{-}setpt} < T_{dp\text{-}outdoor} < T_{dpc\text{-}sat}$)
(Refrigerative cooling region, dew-point less than Setpoint Saturation Temperature)

Air in this region must have both sensible heat and moisture (latent heat) removed to maintain the desired setpoint. The amount of moisture removed may be used to determine the amount of latent heat which is removed for humidity control. The sensible and latent energy requirements in this region are defined by equations 1 and 2.

Region 6: Outdoor dry-bulb and dew-point temperatures greater than cooling dry-bulb setpoint temperature and dewpoint at saturation

$T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $t_{dp\text{-}outdoor} > T_{dpc\text{-}sat}$)
(Refrigerative cooling region, dew-point greater than setpoint saturation temp)

Air in this region is hot and humid. The latent (moisture) heat removal is the significant energy requirement to maintain the desired conditions. The sensible and latent energy requirements in this region are defined by equations 1 and 2.

It should be recognized that the energy values presented are for the minimum theoretical enthalpy changes of the air and the total amount of equipment energy used in Regions 4, 5 and 6 may be larger than the theoretical energies given due to the system design and equipment efficiencies.

4. Procedure

Estimates were made of the theoretical amount of energy needed to condition a constant airflow rate of one kg of dry air per hour (kg/h) of outdoor air used for ventilation. These estimates were made using measured hourly weather data from a number of locations and the theoretical energy and moisture change needed to condition the air to the desired statepoint. The weather data for each location were analyzed to determine the number of hours the outdoor air conditions fell within each psychrometric process region and the weighted average air property for each region. The sensible and latent energies required in each of the psychrometric process regions were then determined by calculating the energy difference between the air statepoint representing the average condition for all the hours within that region and the air at the desired setpoint. Energy values from each of the processes were then combined to determine the total energy per unit mass of ventilation. The effects of equipment and different heating and/or cooling techniques are not included due to the wide variety and efficiencies of possible equipment. Summary weather data are provided in [3] to determine these effects if desired.

4.1 Energy Transfer Summary

The sensible energy which must be used over all the psychrometric regions to heat to the desired heating setpoint and cool to the desired cooling setpoint is the sum of the heating and cooling energy requirements, or:

$$Sen_{total} = S_1 + | S_4 + S_5 + S_6 | \quad (4)$$

where S represents equation 1 and the subscript represents the region.

The total latent energy which must be removed to obtain the desired cooling humidity conditions is:

$$Lat_{total} = | L_4 + L_5 + L_6 | \quad (5)$$

where L represents equation 2 and the subscript represents the region.

The theoretical total energy which must be supplied to maintain the desired conditions is the sum of the sensible and latent heat transfers or:

$$Energy_{Total} = Sen_{total} + Lat_{total} \quad (6)$$

4.2 Weather Data Sources

Measured hourly weather data from a number of locations in North America and Europe were used to determine the average outdoor weather conditions. Long-term (30 years) hourly weather data for 238 US locations are available in the SAMSON data set [8]. A subset of these weather data sets was selected based upon their climate classification region [4, 7] to be representative of the range of climates and weather conditions experienced in America [2]. European locations were selected based upon the availability of hourly weather data. Hourly weather data for most of the British locations were obtained from the CIBSE Example Weather Years, EWY [6]. Weather data for other European locations and four additional UK locations were obtained from the CEC Test Reference Years [1]. The selected American and European locations are presented in Table 1.

			Total Heating (MJ·h/kg)	Cooling Sensible (MJ·h/kg)	Cooling Latent (MJ·h/kg)	Total Cooling (MJ·h/kg)	TOTAL HEATING & COOLING (MJ·h/kg)
1	BEL	Bruxelles	73.4	-0.1	-1.0	-1.1	74.5
2	BEL	Oostende	76.0	0.0	0.0	0.0	76.0
3	BEL	Saint-Hubert	101.1	0.0	0.0	0.0	101.1
4	DK	Copenhagen	89.6	0.0	-0.1	-0.1	89.7
5	FR	Carpentras	55.0	-1.8	-3.5	-5.3	60.3
6	FR	Limoges	70.3	-0.3	-0.7	-1.0	71.3
7	FR	Macon	72.4	-0.6	-1.7	-2.3	74.7
8	FR	Nancy	78.7	-0.2	-0.9	-1.1	79.7
9	FR	Nice	40.1	-0.4	-5.1	-5.5	45.6
10	FR	Trappes	74.5	0.0	-0.3	-0.3	74.8
11	GB	Aberdeen	88.2	0.0	0.0	0.0	88.2
12	GB	Aberporth	72.7	0.0	-0.1	-0.1	72.8
13	GB	Aberporth,CEC	73.9	0.0	0.0	0.0	73.9
14	GB	Aldergrove	82.2	0.0	0.0	0.0	82.2
15	GB	Birmingham	77.0	0.0	-0.1	-0.1	77.1
16	GB	Bristol	82.1	0.0	0.0	-0.1	82.2
17	GB	Camborne	67.0	0.0	0.0	0.0	67.0
18	GB	Dundee	84.6	0.0	0.0	0.0	84.6
19	GB	Eskdalemuir	95.1	0.0	0.0	0.0	95.1
20	GB	Eskdalemuir,CEC	96.1	0.0	0.0	0.0	96.1
21	GB	Glasgow	81.2	0.0	-0.1	-0.1	81.2
22	GB	Heathrow	67.6	0.0	-0.2	-0.2	67.8
23	GB	Kew	71.7	0.0	0.0	0.0	71.7
24	GB	Kew, CEC	70.4	0.0	0.0	-0.1	70.5
25	GB	Lerwick, CEC	97.5	0.0	0.0	0.0	97.5
26	GB	Manchester	78.6	0.0	-0.1	-0.1	78.7
27	GB	Newcastle	88.0	0.0	0.0	0.0	88.0
28	GB	Norwich	79.5	0.0	-0.3	-0.4	79.8
29	GB	Sheffield	80.4	0.0	-0.1	-0.1	80.5
30	NL	DeBilt	77.5	-0.1	-0.2	-0.3	77.9
31	NL	Eelde	83.2	0.0	-0.1	-0.1	83.2
32	NL	Vlissingen	69.8	0.0	0.0	0.0	69.9
33	USA	Boston, MA	77.3	-1.4	-5.8	-7.2	84.5
34	USA	Brownsville, TX	10.7	-11.7	-76.4	-88.1	98.7
35	USA	Cheyenne, WY	100.0	-0.1	0.0	-0.1	100.1
36	USA	Ft. Worth, TX	34.9	-10.4	-34.5	-44.9	79.8
37	USA	Lexington, KY	64.9	-2.5	-12.0	-14.5	79.4
38	USA	Los Angeles, CA	20.9	-0.3	-1.0	-1.2	22.1
39	USA	Miami, FL	3.3	-9.9	-82.2	-92.1	95.4
40	USA	Omaha, NE	84.7	-3.6	-14.1	-17.8	102.5
41	USA	Phoenix, AZ	19.5	-20.2	-8.7	-28.8	48.3
42	USA	Salt Lake City, UT	79.2	-2.4	0.7	-1.6	80.8
43	USA	Seattle, WA	67.2	-0.4	-0.4	-0.7	67.9

Note: Negative energy represents energy extracted in cooling.
The total is the sum of the absolute values of heating and cooling.

Table 1: Annual sensible, latent and total energy requirements (MJ.h/kg dry-air)

4.3 Determination of the average condition for each psychrometric region

The "average air" in each psychrometric region for each location was determined by analysing the measured weather data. Coincident matrices or arrays were made which contained the number of hours each dew-point temperature occurred coincidentally with each dry-bulb temperature. These X-Y arrays (X dry-bulb temperature vs Y dew-point temperature) contained the number of occurrences of Y dew-point temperature which had occurred at X dry-bulb temperature. Thirteen (12 monthly and one yearly total) matrices were determined from the long-term weather data for each location. One Deg C bins were used for both dry-bulb and dew-point temperatures.

The "average air" statepoint for each region was then determined from the matrices by assuming that it was a mixing process of all the occurrences of conditions within a psychrometric region. In this situation each dry-bulb/dew-point combination was weighted by the number of hours of occurrence of that condition in the historical data set. Dry-bulb and absolute humidity for the given dew-point were the psychrometric parameters used in the mixing routines. The psychrometric properties were calculated using C++ routines [5, 9]. Standard air pressure based upon station elevation was used for all the mixing calculations.

The average percentage of the annual hours in each psychrometric region and the corresponding average dry-bulb temperature and humidity ratio are given in [3] for each of the locations investigated. The percentage of the total number of hours in each region is given for four locations in the pie charts in Figure 2.

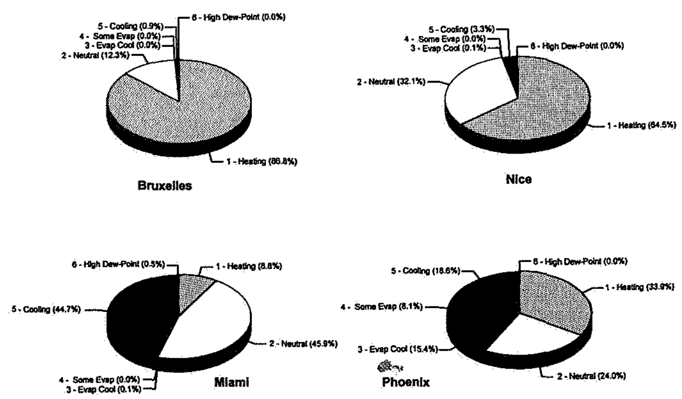

Figure 2: Pie chart with percentage of hours in each psychrometric region

5. Results and Discussion

5.1 Annual heating energy requirements

The amount of sensible heating required for conditioning a constant airflow of one kg-dryair/hr of ventilating air to 18 Deg C was determined for each of the locations and is presented in Table 1. This setpoint was used to closely correspond to a setpoint commonly used in some American standards which relate to air infiltration and ventilation (ASHRAE Standards 119 and 136).

There is a significant amount of energy used to heat the incoming air. For the 18 Deg C setpoint it varies from approximately 101 MJ.h/kg for Saint-Hubert, Belgium (cold climate) to 3.3 MJ.h/kg for Miami, USA (warm climate). These account for 99,6% and 2.3% of the total energy for each location respectively.

Sometimes it is assumed that the entering air needs to be heated to a temperature less than the setpoint due to solar and internal heat gains. A sensitivity analysis of the energy required to heat the air to 1, 2 and 3 degrees less than the setpoint (i.e. 17, 16 and 15 Deg C respectively) was conducted. It was found that for the locations selected in this work which had a significant amount of heating required that there was approximately a 10% (7.2 MJ.h/kg) reduction in this energy for every Deg C of reduction in the setpoint. The expanded version of this work [3] also contains an equation with location dependent coefficients which describe the variation of the heating requirements over a range of setpoints from 5 to 40 Deg C.

5.2 Annual sensible and latent cooling energy requirements

The total theoretical sensible and latent cooling energy exchange required for humidity control and cooling to the desired statepoint of 25.6 Deg C and 40% RH for psychrometric regions 4 through 6 are presented in Table 1. The sensible and latent energy exchange for each of the regions 3 through 6 are contained in [3].

These results indicate that conditioning of air to provide cooling and dehumidification can require significant amounts of energy. The greatest amount of sensible cooling was required in Phoenix, AZ (20.2 MJ.h/kg dry air) and the greatest amount of latent cooling was required in Miami, FL)82.2 MJ.h/kg). The total cooling load (combined sensible and latent) is highest in Miami (92.1 MJ.h/kg) which has a hot humid climate.

On the average (each station weighted evenly), latent cooling required 65.3% of the total cooling load for all the locations investigated. When only those locations requiring more than 5 MJ.h/kg are considered (i.e. consider only those locations typically requiring air conditioning), the latent cooling required 79.7% of the total cooling load. This implies that more energy is used in air conditioning for moisture control than dry-bulb temperature control.

Variation of energy required due to setpoint:

The effect of the cooling dry-bulb temperature setpoint on the energy required was determined by changing the setpoint plus and minus two Deg C for those locations which had greater than 5 MJ.h/kg cooling load. A great sensitivity of the cooling energy requirements to the control setpoint selected was found [3]. The greatest change in energy requirements was for Miami where the cooling energy required at 2 higher and lower setpoints was 151.4% and 49.5% of the energy required at 25.5 Deg C.

Variation of energy required due to humidity design setpoint:

The latent energy requirements previously identified indicate that a significant amount of the energy used is for dehumidifying the air to the desired condition. Thus the design relative humidity greatly impacts the energy requirements. (The energy requirements were determined initially for a 40% relative humidity design.) In order to determine the sensitivity of the relative humidity setting, the energy required for relative humidity designs of 60% and 80% were also determined for the 25.6 Deg C setpoint.

Increasing the relative humidity setpoint from 40% to 60% had a significant impact on the energy requirements for those locations with significant cooling requirements. The energy requirements at 60% RH relative to that required at 40% RH ranged from 15.2% for Carpentras to 59.0% for Brownsville. When the setpoint was raised at 80% there was an even greater reduction in the energy requirements. The fraction of energy required at 80% RH ranged from 0.0% to 21.2% of that when the setpoint was 40% RH.

5.3 Combined annual sensible, latent and total energy requirements per unitary airflow rate

The combined heating and cooling sensible, latent and total energy requirements (based on the 18 Deg C heating, and 25.6 Deg C, 40% cooling setpoints) are presented for each of the locations in Table 1 and Figure 3. This is the total theoretical energy required over the entire year which must be supplied to condition

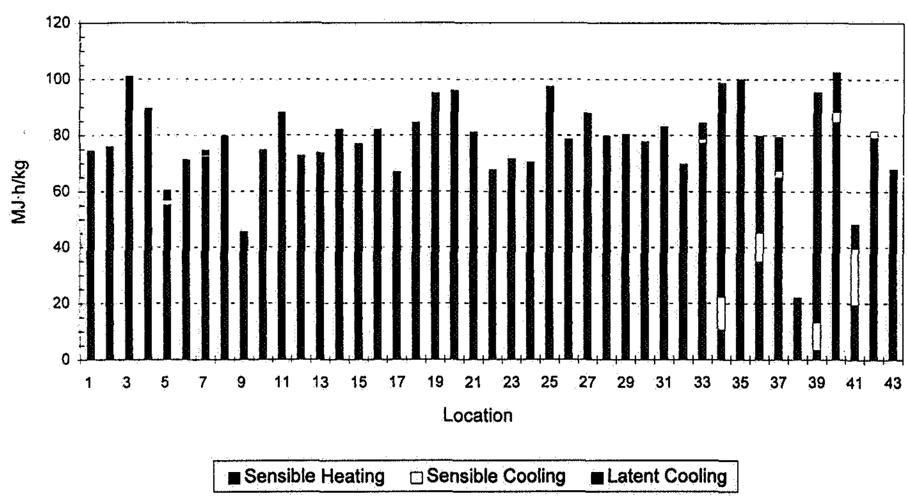

Figure 3: Total energy required for ventilation based upon constant airflow rate (Setpoints: Heating = 18 Deg C, Cooling 25.6 Deg C, 40% RH)

the ventilation air to the desired conditions. The total energy required ranged from 22.1 to 102.5 MJ.h/kg in America (Los Angeles and Omaha) and from 45.6 to 101.1 in Europe (Nice and Saint-Hubert). Heating accounted for almost all the energy used for conditioning ventilating air in Europe with the maximum air conditioning load being 5.5 MJ.h/kg (12.1% of total) in Nice. In America the fraction of the total energy used for cooling varied from 96.5 to 0.1% (92.1 to 0.1 MJ.h/kg for Miami and Cheyenne respectively). The latent load was larger than the sensible load for air conditioning in all the locations with a significant cooling load except Phoenix which has a hot dry climate.

6. Summary

Estimates were made of the theoretical amount of energy needed to condition a constant airflow rate of one kg of dry air per hour (kg/hr) or outdoor air used for ventilation. These estimates were made using measured hourly weather data from a number of locations and the theoretical energy and moisture change needed to condition the air to the desired statepoint. It was found that a significant amount of energy is required to condition air used for ventilation. The annual energy required per kg/hr of airflow varied in America from 22.1 MJ.h/kg for Los Angeles to 102.5 MJ.h/kg for Omaha. In Europe the range was from 45.6 MJ.h/kg for Nice to 101.1 MJ.h/kg for Saint-Hubert. In Europe most of the energy was used to heat the air to the desired setpoint. In America there were significant amounts of both heating and cooling required. Much of the variation was due to the amount of moisture in the air which had to be removed in air conditioning. In situations where air conditioning is used, a significant amount of this energy is used in dehumidifying the air. For example in Miami 86.1% of the energy is used for moisture removal.

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Forthcoming Conferences

Solar Energy in Architecture and Urban Planning 4th European Conference
March 26-29, 1996
Haus der Kulturen der Welt, Berlin, Germany
Contact: Conference Organisation and Coordination, Heinz Ehmann, WIP,
Sylvensteinstrasse 2, D-81369 Muenchen, Germany
Tel: +49 89 720 12 32
Fax: +49 89 720 12 40

7DBMC
7th International Conference on the Durability of Building Materials and Components
19-23 May 1996
Stockholm, Sweden
Contact: Executive Secretariat 7DBMC, Division of Materials Technology, Department of Built Environment, Royal Institute of Technology, PO Box 88, S-801 02 Gavle, Sweden,
Tel: +46 26 14 78 00,
Fax: +46 26 14 78 01

World Renewable Energy Congress IV
15-21 June 1996
Denver, Colorado, USA
Contact: Prof Ali Sayigh, Director General of Wren, 147 Hilmanton, Lower Earley, Reading RG6 4HN, UK,
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Roomvent '96
5th International Conference on Air Distribution in Rooms
July 17-19 1996
Yokohama, Japan
Contact: Conference Secretariat, Roomvent '96, Murakami and Kato Laboratory, Institute of Industrial Science,
University of Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo, 106 Japan
Tel: +81 3 3402 6231 x 2575
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PLEA 96 Louvain-la-neuve
The 13th International Conference on Passive and Low Energy Architecture
Building and Urban Renewal
July 16-18 1996
Louvain-la-neuve, Belgium
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Fax: +35 10 47 45 44
email: deherde@arch.ud.ac.be

Indoor Air '96
7th International Conference on Indoor Air Quality and Climate
July 21-26 1996
Nagoya, Japan
Contact: Dr Koichi Ikeda, Indoor Air '96,
The Institute of Public Health, 6-1, Shirokanedai 4-chome,
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Profiting from Energy Efficiency
ACEEE 1996 Summer Study
August 25-31 1996
Asilomar Conference Center, Pacific Grove, California, USA
Contact: American Council for an Energy-Efficient Economy,
1001 Connecticut Avenue, NW, Suite 801,
Washington, DC 20036, USA

ECCOMAS 96
Second ECCOMAS Conference on Numerical Methods in Engineering/ Third ECCOMAS Computational Fluid Dynamics Conference
9-13 September 1996
Paris, France
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Tel: +33 1 44 27 11, Fax: +33 1 44 27 72 00,
email: eccomas96@ann.jussieu.fr

ICCDR-3
Third International Conference on Carbon Dioxide Removal
September 9-1, 1996
Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
Contact: ICCDR-3 Secretariat, c/o Anne Carbone, MIT Energy Laboratory, Room E40-469, 1 Amherst Street, Cambridge, MA 02139-4307, USA
Tel: +1 617 253 8296
Fax: +1 617 253 8013, email: hjherzog@mit.edu

13th International Symposium on Contamination Control
16-20 September 1996
"Nederlands Congresbouw", The Hague, The Netherlands
Contact: VCCN, Vereniging Contamination Control Nederland, PO Box 1269, 3800, BG Amersfoort, The Netherlands, Tel: +31 33 617496, Fax: +31 33 637050

Optimum Ventilation and Air Flow Control in Buildings
17th Annual AIVC Conference
17-20 September 1996
Hotel 11, Gothenburg, Sweden
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Ab-Sorption '96
International Absorption Heat Pump Conference '96
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Le Centre Sheraton
Montreal, Quebec, Canada
Contact: Dr D Nikanpour/Dr S Hosatte, Organising Committee, CANMET-EDRL, 1615 Montee Ste Julie, PO Box 4800, Varennes, Quebec, Canada, J3X 1S6
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Future Buildings - the Evolving Role of the Services Engineer
29 September - 1 October 1996
Harrogate International Centre,
Harrogate, North Yorkshire, England
Contact: W Stephen Comstock, Ashrae, 1791 Tullie Circle NE, Atlanta, GA 30329, USA

PLEA 1997 Kushiro
The 14th International Conference on Passive and Low Energy Architecture - Bioclimatic Design in Cold Climates
January 8-10 1997
International Conference Hall, Kushiro, Japan
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TECHNICAL NOTES

(Unlisted technical notes have been superceded)
Applications Guide (1986) Air Infiltration Calculation Techniques
Handbook (1983) Air infiltration control in housing
TN 11 (1983) Validation and comparison of mathematical models
TN 13 (1984) Wind pressure data requirements
TN 13.1 (1984) 1984 Wind Pressure Workshop Proceedings
TN 16 (1985) Leakage Distribution in Buildings
TN 17 (1985) Ventilation Strategy - A Selected Bibliography
TN 20 (1987) 'Airborne moisture transfer: workshop proceedings
TN 21 (1987) Review and bibliography of ventilation effectiveness
TN 23 (1988) Inhabitants' behaviour with regard to ventilation
TN 24 (1988) AIVC Measurement Techniques Workshop
TN 25 (1989) Subject analysis of AIRBASE
TN 26 (1989) IEA Annex IX 'Minimum ventilation rates
TN 27 (1990) Infiltration and leakage paths in single family houses
TN 28 (1990) A guide to air change efficiency
TN 28.2 (1991) A guide to contaminant removal effectiveness
TN32 (1991) Reporting guidelines for airflows in buildings
TN33 (1991) A review of building air flow simulation
TN34 (1991) Air flow patterns: measurement techniques.'
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TN 36 (1992) Limb M J 'Airgloss Air Infiltration Glossary'.'
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TN 46 (1995) Limb M J, "1994 Survey of Current Research"
TN 47 (1995) Colliver D, "Energy Requirements for Conditioning of Ventilation Air".

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BIB1 (1993) Ventilation and infiltration characteristics of lift shafts and stair wells
BIB2 (1994) Garage Ventilation: Summarises research into the health, energy and design aspects of the various systems used in garage ventilation.
BIB3 (1994) Natural ventilation: Covers the main elements of natural ventilation research, the fundamental equations, driving forces and associated factors, as well as useful reports which focus on modelling and calculating natural ventilation air flows.
BIB4 (1995) "Air intake positioning to avoid contamination of ventilation air"
BIB5 (1996) "Heat pumps for ventilation exhaust air heat recovery"

AIVC CONFERENCE PROCEEDINGS

AIVC Conference Proceedings nos 1-9 are available as individual papers, or in microfiche form. Details of contents can be forwarded on request.
10th 'Progress and trends in air infiltration and ventilation research' Espoo, Finland, 1989;
11th 'Ventilation System Performance' Belgirate, Italy, 1990;
12th 'Air Movement and Ventilation Control within Buildings', Ottawa, Canada, 1991, 3 volumes.;
13th 'Ventilation for Energy Efficiency and Optimum Indoor Air Quality', France, 1992;
14th 'Energy Impact of Air Infiltration and Ventilation', Denmark, 1993
15th 'The role of ventilation', Buxton, UK, 1994
16th 'Implementing the results of ventilation research', Palm Springs, USA, 1995.

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