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Ventilation and Building Airtightness: an International Comparison of Standards, Codes of Practice and Regulations

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *):

I Load Energy Determination of Buildings*
II Ekistics and Advanced Community Energy Systems*
III Energy Conservation in Residential Buildings*
IV Glasgow Commercial Building Monitoring*
V Air Infiltration and Ventilation Centre
VI Energy Systems and Design of Communities*
VII Local Government Energy Planning*
VIII Inhabitant Behaviour with Regard to Ventilation*
IX Minimum Ventilation Rates*

X Building HVAC Systems Simulation*
XI Energy Auditing*
XII Windows and Fenestration*
XIII Energy Management in Hospitals*
XIV Condensation*
XV Energy Efficiency in Schools*
XVI BEMS - 1: Energy Management Procedures*
XVII BEMS - 2: Evaluation and Emulation Techniques
XVIII Demand Controlled Ventilating Systems*
XIX Low Slope Roof Systems
XX Air Flow Patterns within Buildings*
XXI Thermal Modelling*
XXII Energy Efficient Communities
XXIII Multizone Air Flow Modelling (COMIS)
XXIV Heat Air and Moisture Transfer in Envelopes
XXV Real Time HEVAC Simulation
XXVI Energy Efficient Ventilation of Large Enclosures
XXVII Evaluation and Demonstration of Domestic Ventilation Systems
XXVIII Low Energy Cooling Systems

Annex V Air Infiltration and Ventilation Centre

The IEA Executive Committee (Building and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous aggreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial groundwork the experts group recommended to their executive the formation of an Air Infiltration and Ventilation Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardisation of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and based on a knowledge of work already done to give direction and firm basis for future research in the Participating Countries.

The Participants in this task are Belgium, Canada, Denmark, Germany, Finland, France, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States of America.

Scope and Forward

The purpose of this review of current airtightness and ventilation rate standards is to provide a reference document to all those involved in ventilation and building research. This review summarises available airtightness and minimum ventilation rate requirements in the member countries of the Air Infiltration and Ventilation Centre. It also examines a number of indoor air quality standards. Where uniformity exists in the way the standards are expressed some analysis has also been included. The data contained in this report are also available in database format.

Acknowledgements

The preparation of this report depended on the effort and cooperation of many individuals and organisations, in particular the AIVC Steering Group who provided valuable advice and assistance on its content and structure.

Contents

1 Introduction

Since the mid 1970s a variety of methods has been used to achieve improved levels of energy conservation, indoor air quality and health and safety within the built environment. One such method has been the use of codes, standards and guidelines to steer developments in the market place.

A clear distinction must be made between a standard, a guideline and a code.

A standard is a technical specification or other document available to the public, drawn up with the co-operation and consensus or general approval of all interests affected by it based on the consolidated results of science, technology and experience, aimed at the promotion of optimum community benefits and approved by a body recognized on the national, regional or international level.

A guideline is a document that can include everything a standard can, however it recommends rather than requires.

A code or regulation is a binding document which contains legislative, regulatory or administrative rules and which is adopted and published by an authority legally vested with the necessary power.

Ventilation plays an important role in maintaining optimum air quality in buildings. Primarily ventilation is needed to satisfy the metabolic requirements of occupants and dilute and disperse occupant generated pollutants. It can also be used to control non-occupant generated pollutants such as ozone and heat from office equipment or formaldehyde from furniture etc. Ventilation should only be used as a control measure for these types of pollutants if they cannot be avoided or eliminated. Ventilation can also contribute significantly to energy demand, especially at times in which heating and cooling is needed. Therefore a conflict can arise between increasing ventilation to reduce pollutant and heat loads, or reducing ventilation in order to minimise heat loss and reduce discomfort. As a consequence, requirements and recommendations are being introduced in many countries covering ventilation performance and building airtightness.

The objective of this report is to review these developments and to undertake an international comparison of relevant standards codes and requirements. Where possible these standards have been compared. However in many cases, due to the wide diversity of standards, such an analysis is impractical. Such diversity reflects the differing views on the role of ventilation in controlling indoor air quality. Supporting standards are needed to ensure the efficient provision of ventilation. These include airtightness requirements, component performance standards and standards covering the performance of compounds and sealants.

Section 2 of this report deals with airtightness standards for both whole buildings and components. This section also examines the ways these requirements are expressed and some attempts to compare relevant standards have also been included. In Section 3 minimum ventilation and indoor air quality requirements are examined. The standards and requirements presented in this report have been taken directly from the particular country's standards, guidelines and codes, and appear in Appendix A together with the reference from which they are taken. Details of organisations and institutions that issue the requirements are given in Appendix B.

2. Airtightness Requirements

The optimum performance of a ventilation system as well as energy control and comfort conditions are dependent on the airtightness of the building envelope. This is defined as the volumetric flow rate or air change rate for a building artificially pressurised to, for example 50 Pa, with all purpose provided openings sealed. Excessively leaky buildings will interfere with the performance of modern mechanical systems and will greatly reduce the net efficiency of heat recovery devices. On the other hand, naturally ventilated buildings may require higher levels of permeability in order that sufficient ventilation air is provided.

Airtightness requirements are typically expressed in terms of :

(a) Whole building airtightness (b) Component airtightness

Both express the air flow rate through the building or component at an artificially induced pressure.

No uniformity exits between countries on reference pressures and units of air flow rate. Therefore to make comparisons the following basic airflow equations have been applied:

(1) Orifice Flow

$$Q = C_d A.\left(\frac{2\Delta P}{\rho}\right)^{0.5} \quad [m^3/s] \qquad [2.1]$$

Where

C_d = discharge coefficient of opening
A = flow area (m^2)
ΔP = pressure difference across opening (Pa)
ρ = air density (Kg/m^3)

(2) Power Law Flow

$$Q = k.(\Delta P)^n \qquad [m^3/s] \qquad [2.2]$$

Where

Q = air flow rate (m^3/s)
k = flow coefficient (m^3/s at 1 Pa)
n = flow exponent.
ΔP = pressure difference across an opening (Pa)

(3) Equivalent Leakage Area

$$L_n = 1000 \cdot \left(\frac{Le}{A}\right) \cdot \left(\frac{H}{H_o}\right)^{0.3} \qquad [2.3]$$

Where

L_n = normalised leakage.
H_o = height of single story (2.5 m).
H = height of building (m).
Le = leakage area of space (m^2)
A = floor area space (m^2)
(Reference Pressure of 4 Pa)

An overview of current airtightness standards, codes and recommendations is summarised in Table 2.1. This contains whole building and component data at stated reference pressures. References for these data are reviewed in Appendix A and are discussed in Sections 2.1 and 2.2.

Table 2.1 Overview of Current Airtightness Levels in Standards and Regulations. [References are contained in Appendix A]

Country	Whole Building	Components	
		Windows	Doors
Belgium	< 3ach for dwellings fitted with bal.mech.at 50 Pa. <1 ach when heat rec.is fitted at 50 Pa.	2 - 6 m^3/h per metre length of crack at 100Pa	20-40 m3/h per door at 10 or 50 Pa.
Canada	Maximum 1.5 ach at 50 Pa (For HUDAC constructed dwelling)	Extreme 0.25 - 8.35 $m^3/h.m$ at 75 Pa Normal 0.55 - 2.79 $m^3/h.m$ at 75 Pa	2.54 l/s .m^2 of door area at 75 Pa
Denmark		0.5 $dm^3/s.m$ length of joint at 30 Pa 0.4 - 0.7 ach for dwellings	0.50 $dm^3/s.m$ length of crack at 50 Pa
Finland		<0.5 - >2.5 $m^3/h.\ m^2$ at 50 Pa	
France	Max. 0.2 ach for non residential buildings	<7.0 - 60 $m^3/h.\ m^2$ at 100 Pa	<7 - 60 $m^3/h.\ m^2$ at 100 Pa
Germany		1 - 20 $m^3/h.$ m length of joint depending upon exposure level over the pressure range 10 -1000 Pa	
Italy	1 m^2 of envelope should not exceed 10 m^3/h at 98 Pa 1.5 - 5.0 ach for schools	1.4 - 8.0 $m^3/h.$ m (Crack) at 50 Pa 4.8 - 31 $m^3/h.\ m^2$ (Area) at 50 Pa	
Netherlands	Class 1 Max. 100 - 200 dm^3/s at 10 Pa (1.4 - 2.24 ACH at 10 Pa) Class 1 Min. 30 - 50 dm^3/s (0.4 - 0.72 ACH at 10 Pa) Class 2 Max. upto 80 dm^3/s (0.72 - 1.15 ACH at 10 Pa)	2.5 dm^3/s per m length of crack at 75 Pa 0.5 dm^3/s per 100 mm of frame section	
New Zealand		0.6 - 4.0 $dm^3/s.$ m of joint at 150 Pa 2.0 - 17.0 $dm^3/s\ .m^2$ window area at 150 Pa	
Norway	1.5 - 4.0 ach at 50 Pa		
Sweden	3 - 6 $m^3/h\ m^2$ at 50 Pa		
Switzerland	Lower limit 2 - 2.5 ach at 50 Pa Upper limit 3 - 4.5 ach at 50 Pa. NOTE Upper limit for Buildings with balanced mech. is 1 ACH at 50 Pa	0.2 $m^3/h.m$ at 1 Pa (When n=0.66) (a)5.65 $m^3/h.m$ at 150 Pa (b)8.95 $m^3/h.m$ at 300 Pa (c)14.25 $m^3/h.m$ at 600 Pa	
United Kingdom		1.22 - 6.2 at 50 Pa m^3/h m of open joint	
United States of America	Normalised leakage range taken from measurements at 4 Pa ELA for whole of USA. From <0.1 - 1.60 (from ASHRAE 119-1988, APP.B ACH=Ln. Therefore <0.1 to 1.6 ach) NOTE: Standard requires no part of US to be tighter than 0.28 (only small part of upper midwest) Mostly the tightness requirement is 0.4.	0.77 dm^3/s per m of sash at 75 Pa	2.5 - 6.35 dm^3/per m^2 area at 75 Pa 17.0 dm^3/s per m length of crack at 75 Pa

2.1 Whole Building Airtightness

Airtightness is frequently expressed in terms of a whole building leakage rate at an artificially induced pressure (usually 50 Pa). The basis of this pressure is that it is sufficiently large to prevent naturally occurring pressures from influencing the result but is not so large that cracks and gaps are not distorted by the applied pressure. To enable a comparison between whole building values the conversion equations (2.1 to 2.3) have been applied to convert requirements to a 50 Pa reference pressure. The results for maximum air tightness and minimum airtightness values are summarised in Tables 2.2 and 2.3

The Italian standard applies to schools only, and the recommendation of the ASHRAE Standard 119-1988(RA) in the United States is not yet a legal requirement. Figure 2.1 shows those countries that express their requirements as an air change rate per hour at a specified pressure differential, while Figure 2.2 shows the same values normalised to 50 Pa pressure differential.

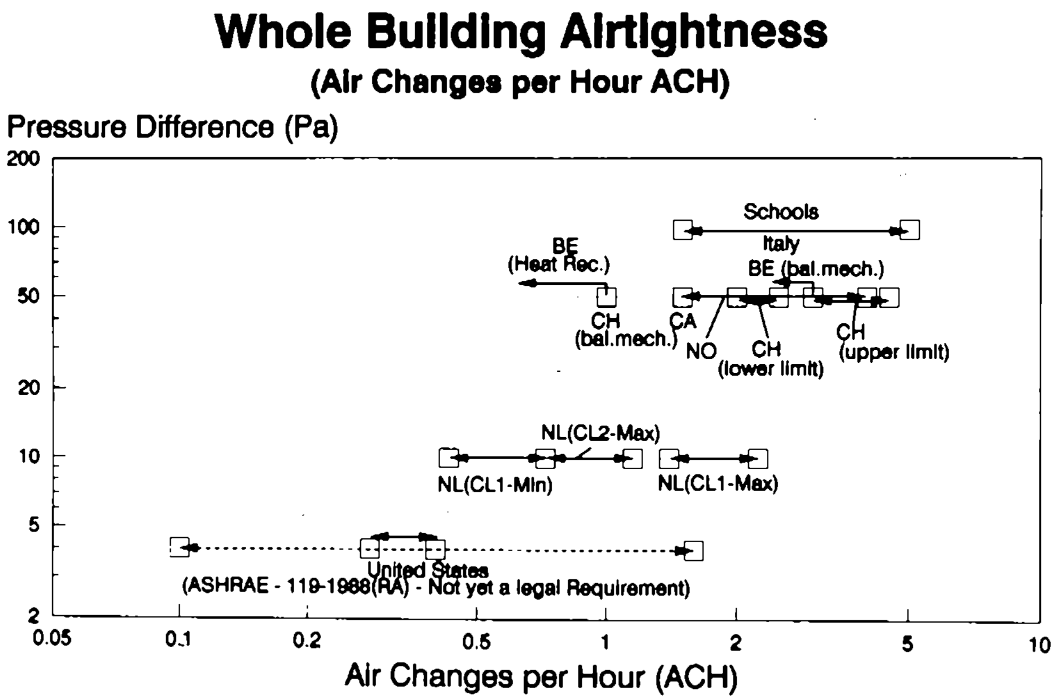

Figure 2.1

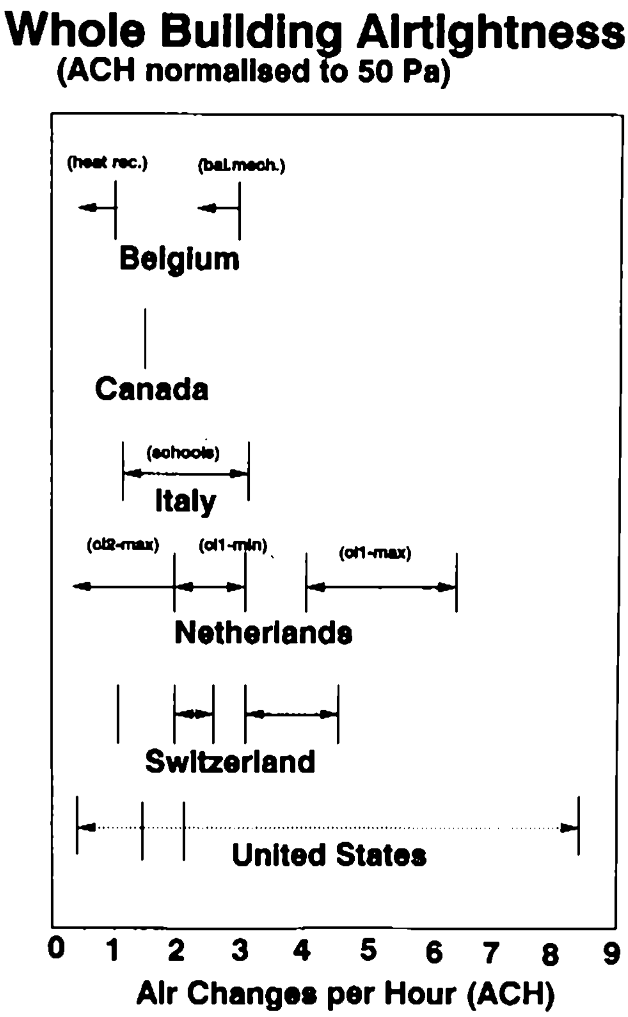

Figure 2.2

From this comparison it can be seen that five countries have normalised minimum whole building air leakage requirements between 1.0 and 1.5 air changes per hour. The Swiss requirement is 2.0 air changes per hour although the standard stresses that the values given are initial values and work is already underway to refine them. In the United States the minimum whole building air leakage standard requires no part of the US to be tighter than 0.28 ACH at 4 Pa (1.5 ach at 50 Pa) (only a small part of the upper Mid-West) mostly the tightness requirement is 0.4 ACH at 4 Pa equivalent to 2.1 ach at 50 Pa. This is comparable to the requirement of Switzerland.

Table 2.2 A comparison of flow coefficients and air change rates from maximum airtightness standards for whole buildings. (In certain cases only applicable to certain ventilation systems.)

Country	ACH (Min) at specified pressure difference (ΔP)	Calculated flow coefficient k, (m^3/s) at specified air change rate and ΔP	Normalised air change rate to 50 Pa
Belgium (BE)(heat. rec.)	1.0 ACH at 50 Pa	0.076	1.0 ACH at 50 Pa
Canada (CA)	1.5 ACH at 50 Pa	0.114	1.5 ACH at 50 Pa
Italy (Schools)	1.5 ACH at 98 Pa	0.073	1.0 ACH at 50 Pa
Netherlands (NL)(CL1-Min)	0.4 ACH at 10 Pa	0.088	1.2 ACH at 50 Pa
Norway (NO)	1.5 ACH at 50 Pa	0.113	1.5 ACH at 50 Pa
Switzerland (CH)(lower limit)	2.0 ACH at 50 Pa	0.15	2.0 ACH at 50 Pa
Switzerland (CH)(bal.mech.)	1.0 ACH at 50 Pa	0.076	1.0 ACH at 50 Pa
United States	0.4 ACH at 4 Pa	0.16	2.12 ACH at 50 Pa

Table 2.3 A comparison of flow coefficients and air change rates from minimum airtightness standards for whole buildings. (In certain cases only applicable to certain ventilation systems.)

Country	ACH (Min) at specified pressure difference (ΔP)	Calculated flow coefficient k, (m^3/s) at specified air change rate and ΔP	Normalised air change rate to 50 Pa
Belgium (BE) (bal.mech.)	3.0 ACH at 50 Pa	0.227	3.0 ACH at 50 Pa
Canada (CA)	1.5 ACH at 50 Pa	0.114	1.5 ACH at 50 Pa
Italy (Schools)	5.0 ACH at 98 Pa	0.243	3.2 ACH at 50 Pa
Netherlands (NL)(CL1-Max)	2.24 ACH at 10 Pa	0.49	6.5 ACH at 50 Pa
Netherlands (NL)(CL2-Max)	1.15 ACH at 10 Pa	0.252	3.3 ACH at 50 Pa
Norway (NO)	4.0 ACH at 50 Pa	0.303	4.0 ACH at 50 Pa
Switzerland (CH)(lower limit)	2.5 ACH at 50 Pa	0.189	2.5 ACH at 50 Pa
Switzerland (CH)(upper limit)	4.5 ACH at 50 Pa	0.34	4.5 ACH at 50 Pa
United States	0.4 ACH at 4 Pa	0.16	2.12 ACH at 50 Pa

From the minimum airtightness table it can be seen that Canada specifies the most stringent standard of 1.5 air changes per hour at 50 Pa, while the minimum specified airtightness for the Netherlands is 2.24 ACH at 10 Pa (when normalised is equivalent to 6.5 air changes per hour at 50 Pa). The remaining countries specify minimum airtightness requirements between these two extremes. All of these standards are for dwellings except the Italian standard which only applies to schools.

The Netherlands express their requirements as an air leakage rate in dm^3/s at 10 Pa, but also relate these specific leakage rates to a given building volume. Flow rates are expressed for two building volumes 250 and 500 m^3. These have been converted to ACH at 10 Pa and appear in Tables 2.2 and 2.3. These values have also been normalised to 50 Pa, and can be seen in Appendix A.

Four countries express their requirements in terms of air flow for each m^2 of surface (e.g. $m^3/m^2.h$). These can be seen in Figure 2.3. Sweden has recently changed its standard, which previously was expressed as an air change rate, but now is expressed in $m^3/m^2.h$ of envelope area and applies to all buildings. These air leakage requirements can be compared to those countries' requirements which express them as an air leakage rate. Assuming a typical building volume of $300m^3$ with a surface area of $250m^2$ air leakage rates can be compared. Sweden's requirements equate to 2.5 to 5 ACH at 50Pa. These values are equivalent to those given in Tables 2.2 and Table 2.3. The United States express air leakage as a normalised leakage area at 4 Pa.

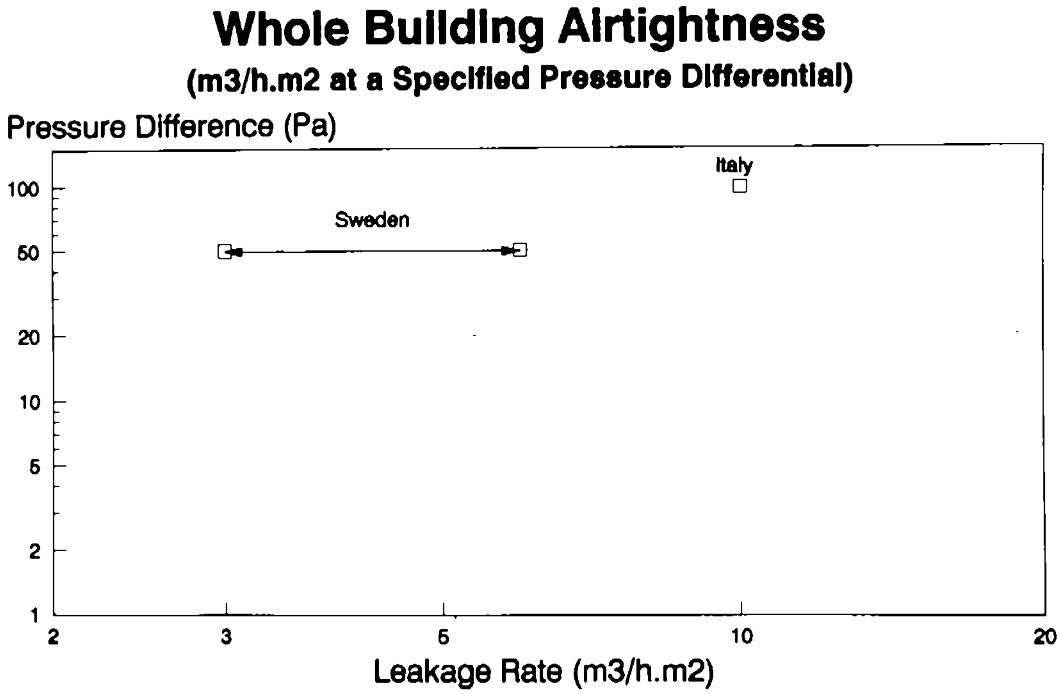

Figure 2.3

There is no French requirement for the airtightness of whole buildings, but the French thermal regulations require calculation of the ventilation heat losses, therefore the air leakage value of the whole building has to be assessed. The whole building leakage value is determined, according to DTU Regles ThG April 1991, as the sum of the air permeability of the ventilation openings and leakage values of the doors, the windows, and the opaque components of the building envelope. Assuming a typical single family dwelling with surface area of 80 m^2 (4 habitable rooms), the air leakage rate including air permeability of inlets is 5.1 ACH at 50 Pa. For a typical flat with surface area of 65m^2 (3 habitable rooms) the value is 3.6 ach at 50 Pa.

It can be seen from the above analysis that despite whole building air leakage requirements being stated in different units and often at different pressure differentials, they do in fact impose similar restrictions to air leakage.

2.2 Components Airtightness.

Standards, codes and recommendations apply to windows, doors and other building components such as floors, walls etc. These are summarised in Sections 2.2.1 to 2.2.3.

2.2.1 Windows.

Twelve countries in this review currently have requirements for the airtightness of windows, expressed in either m^3/h per m^2 area of window or m^3/h per metre length of joint at specific pressure differences. A direct comparison between m^3/h.m and m^3/h.m^2 standards is not possible due to the wide variation in window sizes.

Countries give window leakage requirements in grades of windows, for example Belgian and Dutch standards classify permissible leakage according the overall height of the building or location (coastal, inland etc.). Other countries have grading systems for windows without specific applications for each particular grade. In some countries airtightness performance is expressed over a pressure range while in others values at a specific pressure are given.

Figure 2.4 summarises window airtightness values expressed in m^3/h per metre of joint. It can be seen that the air leakage requirements through windows are expressed over a variety of pressure differentials. Some countries specify grades of window at one pressure (for example Belgium) while others specify window leakage values over a range of pressures (for example the United Kingdom).

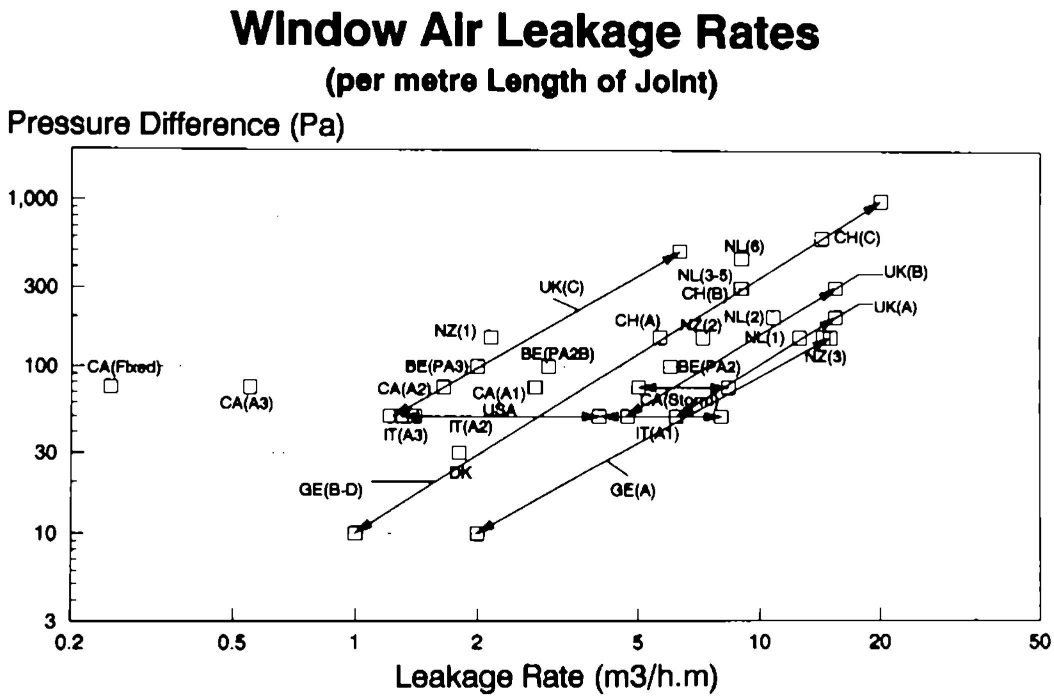

Figure 2.4

For comparison purposes equations 2.1 to 2.3 have been used to calculate the flow requirements at a reference pressure of 1 Pa. These results are summarised in Figure 2.4. It can be seen that the range of flow coefficients (k), varies between 0.015 CA(Fixed) to 0.61 IT(A1). The lower the value of k, the more stringent the requirement and the tighter the window has to be in order to meet the requirement. Over 90% of the recommended air leakage rates have corresponding flow coefficients k, which lie within the range 0.1 - 0.61. Canada has six classes of windows, two of which with k values between 0.015 and 0.032. These are very stringent requirements and represent special cases.

A similar exercise has been carried out in Figure 2.5 for the standards based on unit area leakage ($m^3/h.\ m^2$). It can be seen from this figure, flow coefficients range from 0.04 (SF1) to 2.9 France (A2). Over 90% of specified air leakage rates have corresponding flow coefficients k, which lie within the range 0.33 France(A3) to 2.9 France (A1). Those standard requirements which lie outside this range are for Finland (0.04 to 0.189) and again represent special cases.

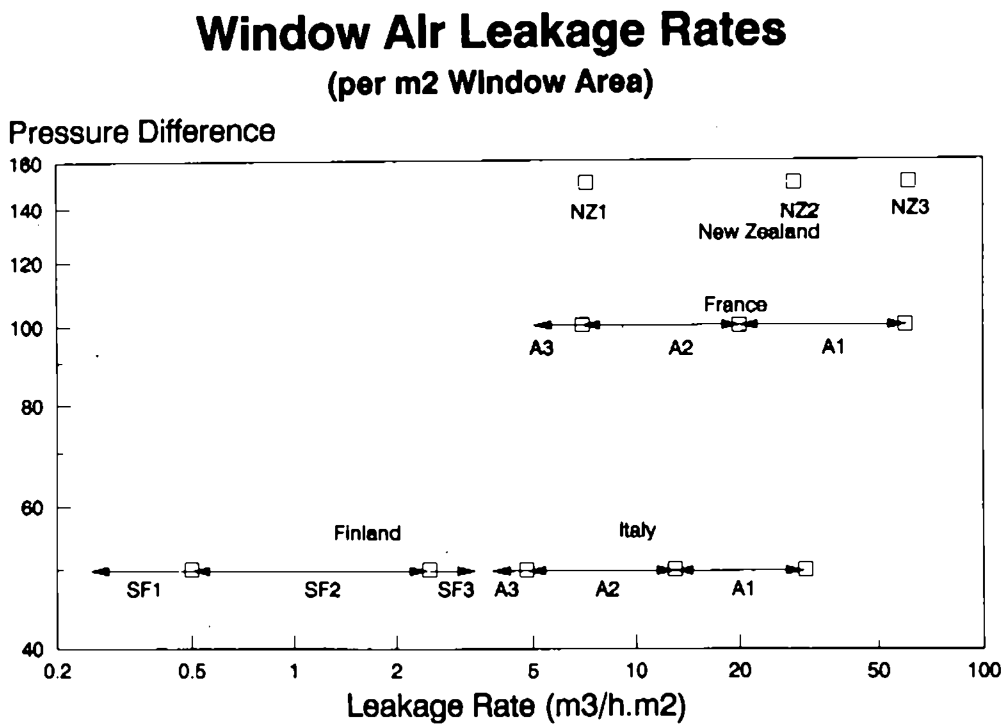

Figure 2.5

Comparing the flow coefficients k, for standards shown in Figures 2.2 and 2.3, similar levels of air leakage restriction are achieved by the imposition of most standards. Those that would achieve higher levels of airtightness represent extreme or special cases.

2.2.2 Doors

Currently only Belgium, Canada, Denmark, France (Draft), and the United States have requirements for doors. These are reviewed in Figure 2.6, where leakage requirements are expressed in m^3/h per m^2 of door area. The distinction between types of doors are only specified for Canada (glass aluminum frame sliding doors) and the United States of America (Sliding glass door; Entrance swing door; Swing, Revolving sliding).

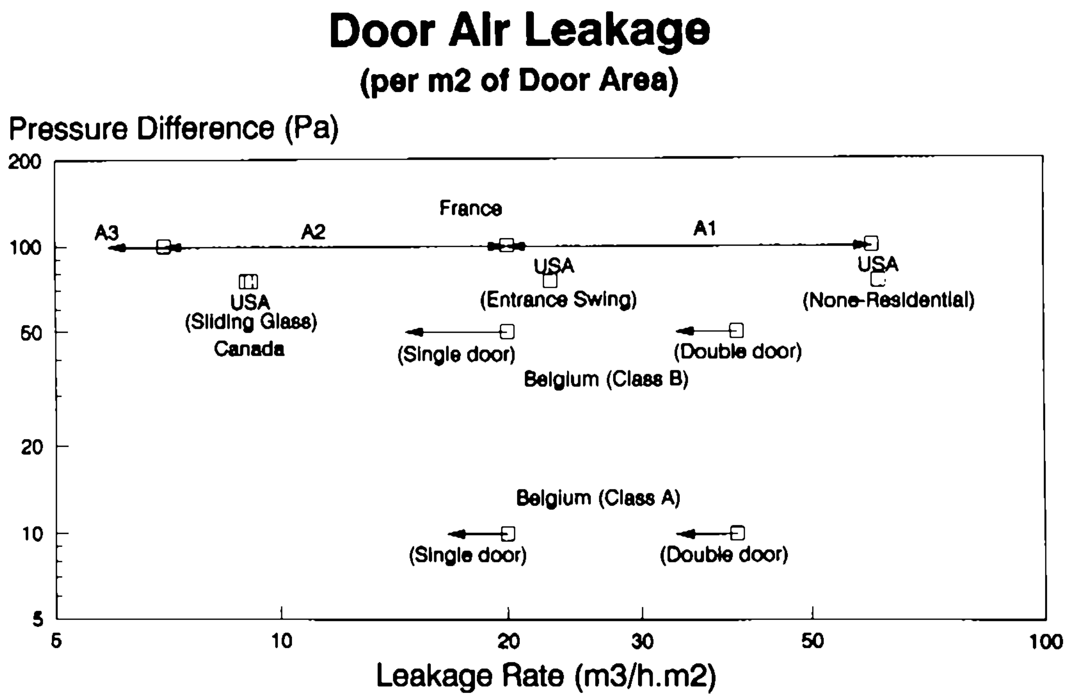

Figure 2.6

The Canadian standard gives leakage requirements in litres per second (l/s) per m^2 of door area, while the United States gives its requirements in dm^3/m^2 of door area at 75 Pa. Both of these values have been converted to m^3/h per m^2 of door area. The Danish requirement of 0.5 dm^3/s is given per metre length of crack at 50 Pa. This is equivalent to 1.8 m^3/h per metre length of crack at 50 Pa. The Belgian requirement is given directly in m^3/h per m^2 of door area.

2.2.3 Other Components.

Ceilings and Floors.

Norwegian Building Regulations stipulate a maximum air leakage rate at 50 Pa or 0.4 $m^3/h.m^2$ of wall, ceiling or floor area. While Dutch requirements specify a maximum air leakage rate of 20E-6 m^3/s m^2 at 1 Pa for floors.

Opaque Walls.

In order to calculate ventilation heat losses, French Building Regulations, according to DTU Regles ThG April 1991, stipulate that the air leakage rate of opaque external walls of the dwelling is:

Single family dwellings: 0.5 $m^3/h.m^2$ for DP = 1 Pa.
Multifamily dwellings: 0.25 $m^3/h.m^2$ for DP = 1 Pa.
The values are given for $1m^2$ of dwelling surface area.

2.3 Techniques for Measuring Airtightness

2.3.1 Whole Buildings

Seven countries have standardised test methods for the measurement of whole building leakages. All except ASTM E741-1983 (RA90) (under revision) use the fan pressurisation method, outlined by Roulet (1991).

Fan pressurisation is a test method involving the generation of measured air flow rates to produce a range of pressure differences between the inside and outside of the building. The Canadian standard is the most detailed, but limits the testing to depressurisation, the others specify tests with both negative and positive pressures. Before pressurisation takes place, all purpose provided openings and vents should be sealed. Some countries, such as Canada for example, give details of the preparations required for all such sealing of openings.

The United States ASTM E741-1983 (RA90) (under revision) standard describes tracer gas techniques for the measurement of air change rates of whole buildings, detailed descriptions of these have also been reviewed by Roulet (1991). The ASTM E471-1983 (RA90) standard specifies the introduction of a tracer gas into a building, being thoroughly mixed with the internal air and then sampled over a period of time. Safety precautions and common tracer gases are also given, along with alternative methods for analysing the decay of tracer gas concentrations from which the air change is determined.

All test method standards specify the presentation of test results as a plot of air flow rate against pressure difference.

2.3.2 Components

Nine countries have test methods for the measurement of air leakage from building components and two international standards also exist. All standards used to determine the air leakage of building components employ the same procedure. The component (window or door) under test, is installed in an opening of a laboratory chamber, controlled pressures are then applied from within the chamber. Pressure is applied in stages of 50, 100, 150, 200, 300 and at 100 Pa intervals thereafter up to a maximum test pressure difference (usually 1000 Pa). The international and other national standards include the reversal of pressure as an option, whereas the Swedish test procedure specifies tests with pressure differences in the opposite direction. More detailed reviews of these techniques are contained in a report by Roulet (1991).

3 Minimum Ventilation Rate Requirements

Ventilation requirements have been introduced to ensure the quality of indoor air.

3.1 Ventilation For Basic Needs

Ventilation for basic needs is the basis for most ventilation requirements. Table 3.1 outlines the current minimum ventilation requirements for dwellings. It can be seen from this table that seven countries have specifications for whole buildings, while most specify ventilation rates for individual rooms. Correlation between specified minimum ventilation rates is difficult because of the way some countries specify their requirements. Some give ventilation rates per person, others just specify a flow rate per m^3/s or per hour while others use air changes per hour.

However by assuming a typical building volume and typical occupancy levels values for whole building ventilation rates can be compared, normalised in terms of air change rates per hour. If four occupants are assumed and a dwelling volume of 300 m^3 with an area of 250 m^2 the following can be considered.

Canada >0.3 ACH
Italy 0.5 ACH (Naturally ventilated residential buildings)
Sweden 1.0 ACH.
United Kingdom Rec: 0.5 - 0.7 ACH
Min: 0.3 - 0.5 ACH
United States 0.35 ACH

It can be seen that air change rates for whole buildings vary between 0.3 and 1.0 ACH. The lowest provision of 0.3 ACH converts to 6.25 litres/second per person. According to the UK standard BS5925, "Ventilation principles and designing for natural ventilation", this is below the minimum requirement for dwellings.

Individual rooms cannot be compared in this way since room volumes and occupancies vary greatly. However from Table 3.1 it can be seen that specified ventilation rates vary between 0.35 l/s and 60 l/s. The highest rates are required for the kitchen and bathrooms, where moisture removal is vital to prevent mould and condensation problems. In living rooms and bedrooms carbon dioxide concentrations are controlled by supplying ventilation air. Insufficient ventilation can lead to occupant lethargy and headache complaints as well as structural problems.

Table 3.1 Minimum Ventilation Rates for Dwellings

Country and Standard Reference	Whole Building (Dwelling) Ventilation Rates	Living Room	Bedroom	Kitchen	Bathroom + WC	WC only
Belgium (NBNB62-003)	0.7 - 1.0 ach 20 30 m^3/h per person		1.0 dm^3/s per m^2 floor area	50-75 m3/h.	14 dm^3/s	7.0 dm^3/s
Canada (CSA F3261-M1989; ASHRAE 62-1989)	>0.3 ach 5 l/s per person			Exhaust 50 l/s (inter.)30 l/s (cont.)	Exhaust 25 l/s (inter.) 15 l/s (cont.)	
Denmark (DS 418)		0.4 - 0.6 ach		0.7 ach	0.7 ach	
Finland (NBC - D2)		0.5 l/s m^2	4.0l/s.person 0.7 l/s m^2floor area	Exhaust 20 l/s	Exhaust 15 l/s	
France (Arrêté 24.03.82)				20- 135 m^3/h	15 - 30 m^3/h	15-30 m^3/h
Germany (DIN 18017; DIN1946; VDI 2088)		Min. 60-120 m^3/h Max. 60-180 m^3/h		Min. 40m^3/h Max. 60m^3/h	Min. 40m^3/h Max. 60m^3/h	Min. 20m^3/h Max 30 m^3/h
Italy (MD 05.07.75)	0.35 - 0.5 ach	15 m^3/h per person		1.0 ach	1.0 - 2.0 ach	
Netherlands (NEN 1087)		1.0 dm^3/s per m^2 floor area	1.0 dm3/s per m^2 floor area	21 dm^3/s	14 dm^3/s	7.0 dm^3/s
New Zealand (ASHRAE 62-1989)	5% of openable window floor area in each room				25 l/s per room (inter.) 10 l/s per room (const.)	
Norway (NBC ch 47 - 1987)		Supply: Openable window or inlet bigger than 100cm^2 in external wall	Supply: Openable window or inlet bigger than 100cm^2 in external wall	Extract: Mech. extract 60 m^3/h or by natural extract at least 150 cm^2 duct above roof	Extract: Mech. extract 60 m^3/h or by natural extract at least 150 cm^2 duct above roof	Extract: Mech extract 40 cm^3/h or by natural extract 100cm^2 duct above roof
Sweden (BFS 1988 18 ch 4.1)	Supply: Min 0.35 l/s m^2 floor area	Supply: 0.35 l/s m2 floor area	Supply: 4.0 l/s person	Extract: 10 l/s.room	Extract: 10 - 30 l/s	Extract: 10 l/s
Switzerland (SIA 384/2, SIA 382/1)			80 - 120 m^3/h		30 - 60 m^3/h	
United Kingdom (BS 5720-1979; BS5925-1991; Build Regs Pt.F; CIBSE Guides A,B)	Rec.12 - 18 l/s.person Min. 8-12 l/s.person	Vent. openings with at least 1/20th floor area and vent openings with total area not less than 4000mm^2	Vent. openings with at least 1/20th floor area and Nat. vent openings with total area not less than 4000mm^2	Mech. supply 60l/s inter or 30l/s cooker hood and Nat. vent openings with total area not less than 4000mm^2 or1ach	15l/s intermit.	1/20th floor area or 3 ach intermit. with overrun
United States of America (ASHRAE 62-1989)	0.35 ach but no less than 7.5 l/s.person			50 l/s (intermit.) or 12 l/s (cont.) or operatable windows	25 l/s per room (intermit.) or10 l/s per room (cont.) or operatable windows	

3.2 Ventilation to Remove Specific Pollutants

People spend a considerable amount of their time in buildings of one type or another. Turiel (1985) suggests this can be as high as 89 - 90%. Ventilation to maintain good indoor air quality is therefore essential to ensure occupant health and comfort.

Indoor air quality is a subjective measure of the indoor air, related to that of the outdoor air, and to the concentration of a number of specified pollutants. The quality of this air is becoming of greater importance, with tighter building envelopes, lower ventilation rates and the use of a wide variety of different building and decorative materials. Some countries specify minimum ventilation rates for basic needs, and to remove the unpleasant nature of carbon dioxide, while other countries turn their attention to the identification and prescription of ventilation rates to remove non occupant emitted pollutants from inside buildings.

Two IEA Annexes have studied the most commonly occurring indoor pollutants, Table 3.2 and Figures 3.1 to 3.4 summarise the findings of both IEA annex 9 and 18. In Table 3.2 annex 9 set out the effects of these pollutants, their concentration limits, control measures, minimum ventilation rates and preferred strategy for their eradication.

Table 3.2 Summary of Recommended Control Measures and Strategies for Indoor Pollutant Control. (Source: IEA Annex 9)

Indoor Pollutant	Effects	Indoor Concentration Limit	Control Measures (Source Control)	Minimum Ventilation Rate	Preferred Strategy
Tobacco Smoke	annoyance, irritation, health risks	annoyance/irritation for healthy person: 1-2 ppm CO	restriction of smoking, separation non-smokers/smokers	50 - 120 m^3 per cigarette or 8 - 20 l/s per person (moderate smoking in large rooms/ offices)	restriction or separation whenever possible, adequate vent. in large public rooms or offices if smoking is allowed
Particles	see above	75µ/m^3 (NAAQS)	see above	17.5 l/s per person (based on average smoking habits)	tobacco smoke is the main source of particles. Strategy as above
Body Odour	annoyance	0.10 % CO_2 (0.15% CO_2)		8.0 l/s per person (3 - 4 l/s per person)	ventilation variable with occupancy predictable variation on statistical basis
Humidity	damage to building fabric	RH below 70% is a necessity, but not sufficient condition	extract ventilation in kitchen and bathroom	appr. 0.5 to 1.0 ach	extract ventilation at main sources and min. whole house vent. rate
Indoor Ionisation Radiation (Radon)	health risks	200-400 Bq/m^3 as action level or rule of ALARA	sealing to the soil, avoiding negative pressure gradient	No generally valid ventilation rates	radon from soil: sealing avoiding negative pressure gradient. Radon from building materials: bal. mech. vent.
CombustionProducts	annoyance, irritation, health risks	e.g. WHO-guidelines	replacement of unvented combustion appliances, local extract ventilation	No generally valid ventilation rates	replacement, local extraction, corrective measures for chimney backdraugting like e.g adequate outside air supply

Indoor Pollutant	Effects	Indoor Concentration Limit	Control Measures (Source Control)	Minimum Ventilation Rate	Preferred Strategy
Selected Organic Substances	annoyance, irritation, health risks	for some substances limits have been established	restriction/interdiction of use of carcinogens, limitation of emission rates	No generally valid ventilation rates	product control: restriction/interdiction limitation of emission rates

IEA Annex 18 compared the maximum allowable concentration (MAC) and acceptable indoor concentrations (AIC) of carbon dioxide, carbon monoxide, nitrogen dioxide and formaldehyde in ten countries for its work on demand controlled ventilation systems. Their results can be seen in Figures 3.1 and 3.4. Annex 18 states that the MAC values represent threshold concentration levels in an industrial environment and apply to a limited, usually 8 hour exposure at the working space. They further state that regarding the indoor air quality of offices the air should be almost the quality of the outdoor air, and the contaminant concentrations should be below MAC values. Acceptable indoor concentrations are also given for each pollutant. For concentrations below the AIC the negative health effects are either tolerable or, if no threshold is known, are at least tolerable. The annex notes that these values' limits are only meant for discussion as it is not the task this annex to set limits.

From these figures it can be seen that in all cases the acceptable indoor concentration is far below the maximum allowable concentration. This shows the concern that surrounds the indoor air quality issue. In countries that display no acceptable indoor concentration, no value is given in the tables in Appendix A; this does not mean the AIC is zero.

The threshold levels for carbon dioxide (CO_2) are shown in Figure 3.1. The data for this figure was compiled from ten countries. It is important to distinguish between CO_2 produced by humans (used as an indicator of unpleasantness) and CO_2 produced by other processes, such as fermentation. The IEA Annex 18 report (Raastchen, 1990) states the maximum desirable levels are between 800 and 1500 ppm. Canada, the United States and Finland are the only countries that distinguish between how CO_2 is generated.

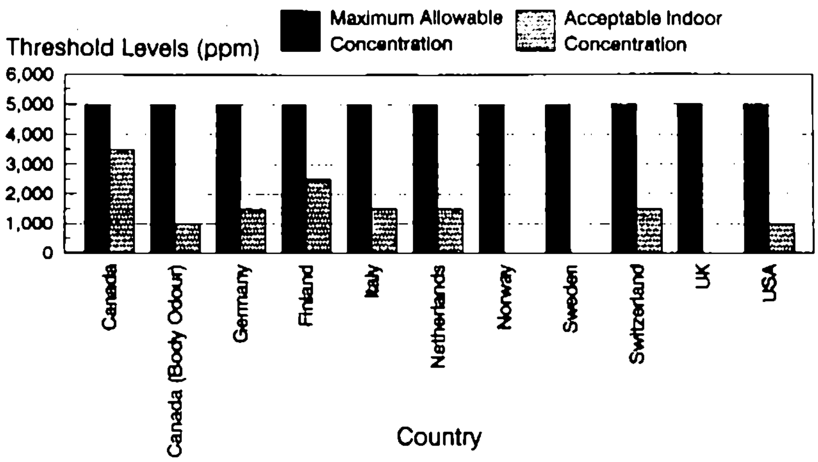

Figure 3.1 Threshold levels for carbon dioxide (CO_2) in different countries

Maximum concentration levels for carbon monoxide (CO) are given in Figure 3.2. Sources of CO in dwellings is tobacco smoke and open fireplaces. From the figure MAC values vary between 25 to 50 ppm. With AIC levels varying between 8.7 and 18 ppm. Annex 18 gave several reasons for the results, the AIC values for Germany reflect the increase in smoking habits, while levels of between 11 and 12 ppm in Canada, Sweden and the United States of America reflect the exposure to CO as a combustion product.

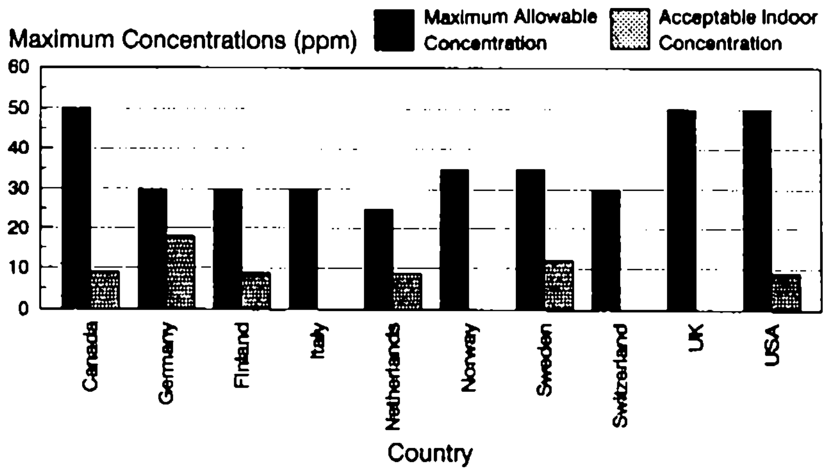

Figure 3.2 Maximum concentration levels for carbon monoxide (CO) in buildings in different countries

Maximum concentration levels of nitrogen dioxide (NO_2) are shown in Figure 3.3. Maximum allowable concentrations vary between 2 and 5 ppm, with acceptable indoor concentrations lower and more constant, varying between 0.08 to 0.3 ppm.

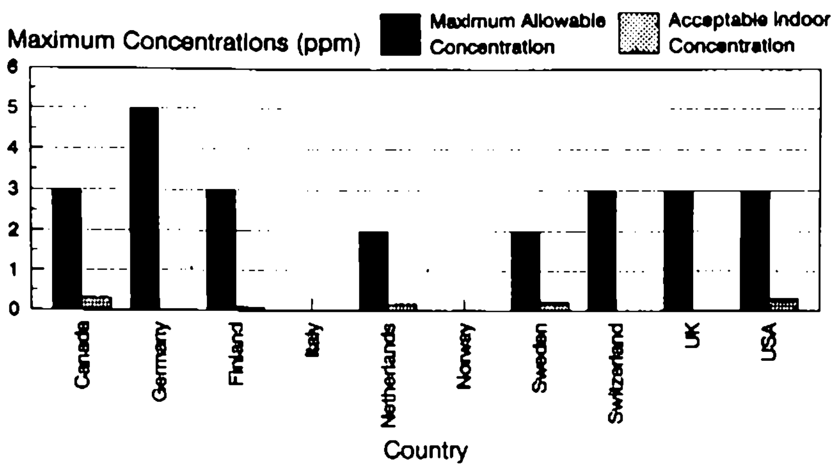

Figure 3.3 Maximum concentration levels for nitrogen dioxide (NO_2) in buildings in different countries

Maximum concentration levels of formaldehyde (HCHO) are outlined in Figure 3.4. Six countries have MAC levels the same as 1 ppm, while Sweden's maximum allowable concentration is 0.5ppm, and the United Kingdom's is 2 ppm. Acceptable indoor concentrations are much lower, in the range 0.1 and 0.34 pm.

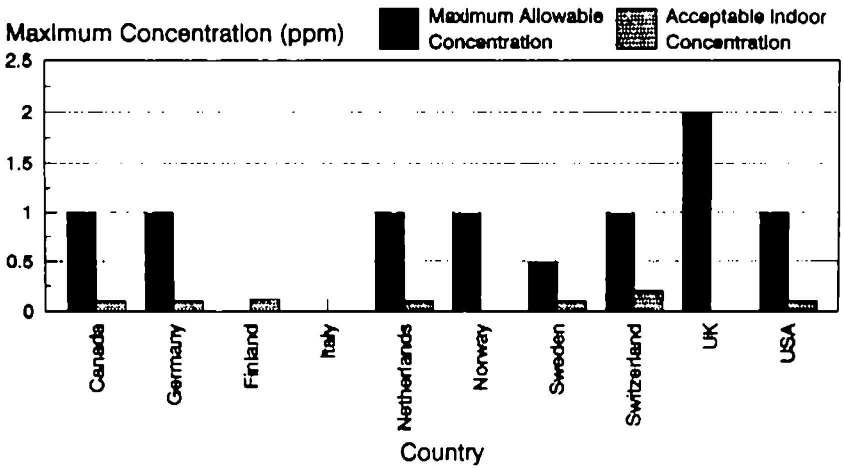

Figure 3.4 Maximum concentration levels for formaldehyde (HCHO) in buildings in different countries

Minimum ventilation rate requirements for offices and schools are outlined in Table 3.3. For schools, requirements are specified to remove carbon dioxide and for basic needs. Requirements are higher than for dwellings with the range varying between 1 and 5 ach and 4 to 10 l/s per person. Differences in the number and age of occupants and level of activity would account for the need for higher ventilation rates.

Office ventilation requirements are specified at present to secure adequate ventilation for basic needs and to remove the harmfulness and unpleasantness of tobacco smoke. All countries except Italy have such requirements, with nine countries specifically having requirements for smoking and non smoking areas. Air supply rates are between 27% and 62% higher for smoking areas compared with those specified for non smoking areas.

Table 3.3 Minimum Ventilation Rate Requirements for Offices and Schools.

Country	Ventilation Rates for Offices	Ventilation Rates for Schools
Belgium	20 m^3/h.person(non-smoking) or 30 m3/h per person (Smoking)	In workplaces 30m^3/h.person
Canada	Minimum 10 l/s.person whether smoking or non smoking(Design occupany). Smoking lounges - 30 l/s.person	8 l/s. person
Denmark	10 l/s.person (smoking) to 4 l/s.person (non-smoking)	
Finland	10 l/s.person (smoking) to 4 l/s.person (non-smoking)	6 - 8 dm^3.person
France	30 m^3/h.person (smoking) 18 m^3/h.person (non-smoking)	15 m^3/h.person
Germany	General 20-30 m^3/h.person	30m^3/h.person
Italy		1.5 - 5.0 ach
Netherlands	55-60 m^3/h.person (smoking) to 35m^3/h.person (non smoking)	5.5 dm^3/s.pupil
New Zealand	Minimum 10 l/s.person whether smoking or non smoking(Design occupany). Smoking lounges - 30 l/s.person	8 l/s.person
Norway	7 l/s per person plus 0.7 l/s per m^2floor area	5.5 l/s.person plus 0.7 l/s.m^2floor area
Sweden	10 l/s.person (smoking) to 5 l/s.person (non-smoking)	10 l/s.person (smoking) to 5 l/s.person (non-smoking)
Switzerland	30 - 70 m^3/h .person(smoking); 25 - 30 m^3/h .person (non-smoking) ; 12 - 15 m^3h . person (non-smoking) NOTE no distinction between schools and offices.	
United Kingdom	8 l/s.person (smoking) to 5 l/s.person (non-smoking)	5 - 8 l/s.person or 1.0 to 2.0 ach

Country	Ventilation Rates for Offices	Ventilation Rates for Schools
Belgium	20 m^3/h.person(non-smoking) or 30 m3/h per person (Smoking)	In workplaces 30m^3/h.person
United States of America	Minimum 10 l/s.person whether smoking or non smoking(Design occupany).Smoking lounges - 30 l/s.person	8 l/s.person

It can be seen that the variation in minimum ventilation rates for dwellings and offices is large. For offices a range of between 4.0 l/s per person for non smoking zones (Finland and Denmark) to 30 l/s per person for smoking areas (United States, New Zealand and Canada) can be noted. While for dwellings ventilation rates are as little as less than 0.3 to 1.0 ach (6.25 to 20.9 l/s per person) for whole buildings and 0.4 l/s to 50 l/s for individual rooms.

4. The Future Development of Ventilation Standards

It is clear from the above review, that despite more countries specifying airtightness and ventilation requirements, little has in fact changed since the early 1980s. The most stringent requirements are imposed by countries that suffer extremes in climate, namely Scandinavia, Canada and Switzerland. Many European countries, for example Netherlands, Italy, Germany and the United Kingdom, specify moderate tightness levels with broad bands depending upon application and location.

Jackman (1984) stated that airtightness and ventilation standards must be introduced in conjunction with good building design to ensure that indoor air quality problems are avoided. Where such stringent standards are specified for very tight building envelopes they are combined with mechanical ventilation and in many cases heat recovery. In countries where the climate is milder, less stringent standards are imposed and natural ventilation combined with moderately airtight envelopes are common. Although in both cases indoor air quality problems have been encountered.

Fanger (1990) presents several reasons why he feels that present ventilation standards do not work as effectively as they might. He argues that many countries continue to assume occupants to be the major or exclusive polluters, and that the supply air quality is the same whether the outdoor air has a high or low quality and finally the indoor air quality aimed at is poorly defined. Recent studies have indicated that the building itself (including furnishing, carpeting and ventilation) is usually a more important pollutant source than the occupant (Fanger, 1990). A step in this direction is offered by the European Concerted Action for indoor air quality and its impact on man (EUR 14449 EN). This document does not prescribe a given quality of outdoor air to be supplied to a space, instead a certain grade of indoor air quality is prescribed to avoid adverse health effects and a decision is required on the level of perceived air quality aimed for in the ventilated space.

The importance of source control to achieve good indoor air quality was discussed by Skaret at the recent Indoor Air 93 Conference held in Finland during July, who described the use of one strategy published by the Nordic Committee on Building Regulation entitled "Indoor Climate - Air Quality". The strategy outlined in the NKB report proposes a nine point plan which includes the selection of building location and construction materials, processes etc that have the lowest pollutant exposures. Ventilation requirements should be ideally based on residual emissions of pollutants and air quality criteria. Bearing this in mind, and the building being considered the main polluter instead of the occupants, a measure of perceived air quality has been developed by Fanger incorporating the olf and decipol concepts.

Fundamentally one decipol is the perceived air quality of one olf (the odour of one standard person) ventilated at 10l/s of fresh air. The NKB recommendations require a perceived air quality of 1.4 Decipol, which equates to 20% dissatisfied. This gives a required air flow rate of 7 l/s.person (equivalent to 7 olf). The NKB therefore recommends the minimum air flow rate with respect to the release of pollutants in offices should not be less than 0.7 l/s per m^2. Although for a given pollutant emitting piece of furniture and or building material this value should be considerably higher. Added to this should be a minimum outdoor air flow rate for sedentary workers of 0.35 l/s person or more. The combined total minimum air flow rate (including basic needs and pollutant load for a given space) should not be less than 7 l/s person. The following example is quoted, for a $10m^2$ room a total air flow rate of 10.5 l/s is required this increases to 20 l/s person when smoking is permitted. In dwellings the airflow rate based on the area of the dwelling may be lower than 0.7 l/s . m^2.

The source control concept is again described by Rengholt at the same conference, who outlined the SCANVAC guidelines "Classified Indoor Climate". The guidelines are divided into a number of sections; three Thermal classes, two air quality classes and two sound level classes. The important point about these guidelines is that ventilation itself has no value, the only values are those of user health and satisfaction. All of the classes are characterised in terms of Percentage Persons Dissatisfied (PPDs). The guidelines also give maximum permitted pollutant concentration levels for carbon monoxide, carbon dioxide, ozone and VOC's. Also given are methods for calculating air flows with respect to pollution from occupants and building materials. Building materials are divided into three classes, low, medium and high pollutant emitting. Air flows of 0.7 to 1.0 l/s m^2 for low emitting materials, are indicated while for high emitting materials more than 5 l/s m^2 could be required (This is considered unrealistic, and so actively discourages the use of such materials).

Other recent attempts to address this issue have been to introduce minimum ventilation rates for the removal of specific pollutants. However these can only be guaranteed with mechanical systems. The introduction of local intermittent exhaust fans into naturally ventilated buildings has been a further attempt to redress the balance. A word of warning is offered by Liddament (1991) who has highlighted the fact that high ventilation rates to remove and dilute indoor air pollutants can be expensive to maintain, the cost of conditioning this high ventilation requirement should be borne in mind when considering the role of ventilation in controlling indoor air quality problems in buildings. Davidge (1986) reviewed ASHRAE guidelines for ventilation and air quality, and noted that they are imposed with the aim of achieving 80% occupant satisfaction, and feels that our reliance on such standards must be subjective, if it is acceptable to allow 20% of occupants to be dissatisfied.

A real comparison of current standards is still hindered by the difference in the way standards are expressed, often leading to confused and incorrect assumptions. Differences in units and methods of expression make it difficult to compare standards, although it can be done with the eventual standardisation of presentation reducing the effort required. Within Europe some attempts are being made to coordinate and harmonise such standards. The International Standards Organisation (ISO) and European Standardisation Committee (CEN) are two organisations already actively involved in this process. Representatives from all the major countries are trying to produce harmonised standards that can be used throughout Europe. For example, ventilation is covered by CEN 156, Ventilation Systems for Buildings, while ASHRAE and the ISO continue to offer a similar service on a more worldwide basis.

It is hoped that such new standards will provide greater clarity and understanding of European situations, while at the same time maintaining the levels of excellence demanded by many countries (Biachina M and Fleury B, 1991).

While every effort has been made to provide the most up to date review possible, standards are constantly being updated, revised and changed. Two standards that are currently in the process of being revised, are ASHRAE 62 and DIN 1946. The revisions where outlined at the recent Indoor Air 93 Conference, held in Finland. Gene Tucker from the USA outlined the proposed alterations to the ASHRAE 62 - 89 standard. A new standard taking into account current scientific knowledge will provide the basis for health and sensory comfort guidance used to define acceptable indoor air quality. The updated standard will emphasise links between sources of contaminants and control of indoor air quality by ventilation, source management and/or cleaning. Possible inclusions are the separate treatment of residential buildings, new emphasis on source management, air cleaning, operation and maintenance over the life cycle of the building and the use of code language to facilitate the standards adoption into building codes. Gene also invited suggestions from interested parties which would be considered by the work group assigned to update this standard.

Alterations to the German Standard DIN 1946 were outlined by Fitzner. Requirements for maximum air velocities, and minimum outdoor air rates estimated by using one of four methods are given. The four methods are

1) person related, (20 - 60 m^3/h) (Offices 40 - 60 m^3/h; lecture rooms 20 - 30 m^3/h).

2) Floor related (Offices 4 - 6 m^3/h per m^2 of floor area, Assembly rooms 10 to 20 m^3 /h per m^2)

3) Particular pollutant concentration limit (ppm), for example a CO_2 concentration of less than 1000 of 1500 ppm is suggested.

Finally

4) for a given perceived air quality (decipol), where high requirements correspond to 0.7 decipol, medium requirement to 1.4 decipol and lower requirements 2.5 decipol.

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Appendix A - Requirements and Standards

A.1 Airtightness Requirements

A.1.1 Whole building leakages

Currently Belgium, Canada, Italy, Netherlands, Norway, Sweden, Switzerland and the United States of America have legislation for the airtightness of whole buildings. The recommendations are briefly outlined below. A draft airtightness standard for France is now being considered as of March 1992, and this is also outlined below.

<u>Belgium</u> Belgian Building Code

Belgium recommends an air leakage rate at 50 Pa of less than 3 ach for dwellings fitted with balanced mechanical ventilation and less than 1 ach when heat recovery devices are fitted.

<u>Canada</u> Single family houses constructed to the specification of the Housing and Urban Development Association of Canada (HUDAC) must have a maximum leakage not exceeding 1.5 ach at 50 Pa. (From Liddament 1991)

<u>France</u> DTU, Règles ThG- April 1991 - Cahiers du CSTB No 2486

(Règles de calcul du coefficient GV des bâtiments d'habitation et du coefficient G1 des bâtiments autre que d'habitation).

There is no French requirement for the airtightness of whole buildings, but the French thermal regulations require calculation of the ventilation heat losses, therefore the air leakage value of the whole building has to be assessed. The whole building leakage value is determined, according to DTU Règles ThG April 1991, as the sum of the air permeability of the ventilation openings and leakage values of the doors, the windows, and the opaque components of the building envelope.

Air permeability of ventilation openings: For an air inlet of which the nominal flow rate is 30 m^3/h at 20 Pa, the air permeability value is 6.8 m^3/h for $\Delta P =$ 1Pa.

Air leakage of doors and windows: the air leakage values are contained between 0.3 and 2.0 m^3/h per m^2 for $\Delta P = 1$ Pa. according to doors and windows classification. The values are given for $1m^2$ of door or window.

Air leakage of opaque components of building envelope: the air leakage value of the whole opaque walls is assumed to be equal to :
Single family dwellings: 0.5 $m^3/h.m^2$ for $\Delta P = 1$ Pa.
Multifamily dwellings: 0.25 $m^3/h.m^2$ for $\Delta P = 1$ Pa.
The values are given for $1m^2$ of dwelling surface area.

<u>Italy</u> Ministerial Decree 02-02-76 Ventilation requirements for schools.

Ministerial Decree 05-07-75 Ventilation requirements for residential buildings.

The Italian Ministerial Decree 02-02-76, ventilation requirements for schools specifies a recommendation for an envelope air leakage value for schools; the infiltration rate across 1 square metre of exterior envelope should not exceed $10m^3/h$ at a pressure difference of 10mm of water (98Pa). It also gives prescribed air change rates of between 1.5 - 5.0 ACH for rooms in school buildings.

While 05-07-75 Ventilation requirements for residential buildings states that all dwellings, bedrooms, living rooms and kitchens must be provided with an openable window of area not less than 1/8th of the floor area, no actual values are given.

Netherlands NEN2687. Air leakage of dwellings - requirements. (Luchtdoorlatendheid van Woningen) - Eisen

This standard only applies to dwellings, but work is currently underway for commercial buildings (NEN 2689). The envelope air leakage rate at 10 Pa, is defined according to the type of ventilation system. The systems fall into 2 classes as laid down in standard NEN1087.

Class 1
System A - Natural Supply and Extract System C - Natural Ventilation Supply with Mechanical Extract
Class 2
System B - Mechanical Supply and Natural Extract System D - Mechanical Supply and Extract

The first table below, outlines the permitted mechanical air leakage at an applied pressure of 10 Pa while the second table lists the minimum permitted leakage.

Maximum Recommended Air Leakage							
	Building Volume (m3) Greater than	Less than	Flow Rate at 10 Pa (dm3/s)	Equivalent to ACH at 10 Pa		Equivalent to ACH at 50 Pa	
Class 1	-	250	100	-	1.4	-	4.16
	250	500	150	2.24	1.12	6.25	3.12
	500	-	200	1.44	-	4.16	-
Class 2	-	250	50	-	0.72	-	2.08
	250	-	80	1.15	-	3.3	-
Minimum Recommended Air Leakage							
	Building Volume (m3) Greater than	Less than	Flow Rate at 10 Pa (dm3/s)	Equivalent to ACH at 10 Pa		Equivalent to ACH at 50 Pa	
Class 1	-	250	30	-	0.43	-	1.24
	250	500	50	0.72	0.36	2.0	1.0
	500	-	50	0.36	-	1.0	-

NOTE: No minimum value given for class two because there needs to be some residual air leakage.

<u>Norway</u> Chapter 53 Norwegian Building Regulations. Thermal Insulation and Airtightness (revised 1987).

Building Regulations of 27th May, 1987. Royal Ministry of Local Government and Labour.

From the Norwegian Buildings regulations the maximum air change rate, at a pressure difference of 50 Pa for buildings, are outlined below:

Norwegian Building Regulations	
Building Type	Air Change Rate per hour at 50 Pa
Detached and terraced single family houses	4.0 ach
Other buildings of not more than two storeys	3.0 ach
Buildings with three or more floors	1.5 ach

<u>Sweden</u> BFS 1988:18 Chapter 3:13,3:14 Airtightness and heat recovery. National Board of Housing and Planning.

BFS 1988:18 gives air leakage values in relation to the average coefficient of air leakage (q_{50}) and a pressure difference of 50 Pa. It states that for that part of the building envelope forming the boundary with outdoor air or an unheated area, the air leakage must not exceed 3 $m^3/(m^2.h)$ for dwellings and 6 $m^3/(m^2.h)$ for other premises.

Switzerland SIA 180 Thermal protection of buildings. Warmeschutz im Hochbau.

SIA 180 gives provisional recommendations for leakage values at a pressure difference of 50 Pa. The values given are initial values and further work is underway to refine them, especially in cases where different parts of the building shell differ considerably as to their leakage. These values are given below in air changes per hour (ach):

Overall leakage of a building opening closed	nL values-1 (ACH) Lower limit	Upper limit
Single family home (with window ventilation)	2.0	4.5
Multi family home (with window ventilation)	2.5	3.5
New homes (with exhaust ventilation)	2.0	3.0
Buildings with balanced ventilation or AC plants	-	1.0

United States of America

ASHRAE 119-1988 (RA)- Air Leakage Performance for Detached Single-Family Residential Buildings.

Single family dwellings based on the climate region in which the dwelling is constructed. Airtightness is specified in the form of normalised leakage; Ln, taking into account building height, floor area and leakage area at a reference pressure of 4Pa. This standard has not yet been adopted by any state of the United States and is therefore not currently a legal requirement.

Classification of leakage is given for a range of normalised leakage based on the following equation:

Ln = 1000 (L/A)(H/Ho)0.3

Where

Ln = the normalised leakage (ELA/Floor area)
Ho = the height of the single storey (8ft)[2.5m]
H = the height of the building (ft) [m]

L = the leakage area of the space (ft^2) [m2]
A = the floor area of the space (ft^2) [m^2]

Classification of leakage.

Classification of leakage.	
Normalised leakage range	Leakage Class
Ln<0.1	A
0.10 ≤Ln<0.14	B
0.14 ≤Ln<0.20	C
0.20 ≤Ln<0.28	D
0.28 ≤Ln<0.40	E
0.40 ≤Ln<0.57	F
0.57 ≤Ln<0.80	G
0.80 ≤Ln<1.13	H
1.13 ≤Ln<1.60	I
1.60 <Ln	J

Maps and tables show the regions and cities which have been given a leakage class based on the normalised leakage range.

NOTE: The standard requires no part of the US to be tighter than 0.28 ach at 4 Pa (equivalent to 1.5 ach at 50 Pa) and that is only required for a tiny part of the upper Mid west; mostly the tightness requirement is 0.4 ach at 4 Pa (equivalent to 2.2 ach at 50 Pa).

A.1.2 Component leakages

Canada, France and the United States have recommendations for doors and windows, while the remaining countries have recommendations for windows only. Sweden and Norway have dropped their window, door and facade requirements and instead have whole building air leakage requirements.

A.1.2.1 Windows

Belgium — STS 52.0 External joinery - general principles.(Menuiseries Extérieures - Generalities) INL 1985.

The requirement for doors applies for all construction works where the requirements of STS 52.0 must be met: this is in practice all governmental buildings and social dwellings.

The standard gives the maximum rate of leakage at 100 Pa for different grades of window shown in the table below.

	Window Classification		
	PA2(1)(2)	PA2B(2)	PA3
Exposure level - height of building in which the window is situated	0-10.0m	10.0-18.0 m	>18.0 m
Air permeability of joints per metre crack length at 100 Pa (m3/h.m)	3	3	2

Remarks:

(1) If a lower thermal and/or acoustical performance is accepted, the class PA2 can be allowed. This corresponds with 6 m^3/h per metre at 100 Pa.
(2) In case the room is equipped with air conditioning the class PA3 is always required.

<u>Canada</u> CAN 3-A440-M84 Windows.Building Materials and Products.

This standard applies to both fixed and openable windows, values are given below across a 75 Pa pressure differential.

Window Rating	Maximum Air Leakage Rate (m3/h.m) at 75 Pa
Storm	8.35 (maximum) 5.00 (minimum)
A1	2.79
A2	1.65
A3	0.55
Fixed	0.25

Notes:

A1 - Intended for use in low rise residential houses, industrial and commercial buildings.
A2 - Intended for use primarily in medium to high rise houses and light industrial and commercial use.
A3 - Intended for high performance institutional and commercial buildings.

Denmark

The Danish Building Regulations (Bygningsreglement 1982), Ministry of Housing, Copenhagen. 1982.

DS 418 - Calculations of heat loss from buildings. (Beregning af bygningerts vermatab). 1977

The Danish Building Regulations state that where the airtightness of doors and windows is not known an air leakage value of $0.5dm^3/s.m$ length of joint at 30 Pa should be assumed. (Equates to $2.6\ m^3/h$. m length of joint at 50Pa)

Standard DS 418 gives a method for calculating heat loss and assumes an air change rate of 0.4 ach for tight living rooms, 0.6 ach for normal living rooms and 0.7 ach for kitchens and bathrooms.

Finland

SFS 3304 Window, functional requirements, clarification and testing, 1978. (in Finnish).

The Finnish classification for window airtightness (SFS 3304) is voluntary, but is widely used among window manufacturers and builders.The values are given in $m^3/h\ m^2$ at a pressure differential of 50 Pa, and are outlined below:

	Airtightness at 50 Pa pressure difference
Window Class 1	<0.5 m3/h.m2
Window Class 2	0.5 - 2.5 m3/h.m2
Window Class 3	>2.5 m3/h.m2

France

France Standard NF P 20-302. Windows Characteristics. (Caractéristiques des fenêtres) April 1980.

Window Classification	Quoted values (m3/h m2) at 100Pa
A1	20 to 60
A2	7 to 20
A3	less than 7

Leakage flow rates are divided by window area. Exponent of the flow rate pressure drop relationship is taken as 2/3rds (0.66). The above classification is defined in NF P 20-302 with reference to windows. This standard is also used for doors.

Germany

DIN 180 55. Windows. Air permeability of joints, water tightness and mechanical strain, requirements and testing. (Fenster. Fugendurchlassigkeit, Schlargegendichtheit und mechanische Beanspruchung Anforderungen und Prufung). October 1981.

This standard classifies windows by exposure level and gives acceptable air permeability values for each group under pressure, over the range 10 to 1000 Pa pressure difference.

Exposure Level		Range of Pressure difference 10 to 1000Pa v=in m3/h.m length of crack					
		10	50	100	150	300	1000
A	v=	2	6	9.5	15.0	-	-
B - D	v=	1	3	4.8	6.0	10.0	20.0

<u>Italy</u> UNI 7979 Classification of window performance.

The Italian standard UNI 7979 classifies external vertical windows according to air permeability, water tightness and resistance to wind action. As regards air permeability windows are classified into three categories A1,2 and 3 in ascending order of air tightness. Given in two formats (Airflow rate per unit length of opening(m^3/h.m); and Air flow rate per unit area of window (m^3/h. m^2))

	Air flow rate per unit length of opening (m3/h.m) at 50 Pa	Airflow rate per unit area of window (m3/h.m2) (m3/h.m2 at 50 Pa
A1	4.0 - 8.0	13.0 - 31.0
A2	1.3 - 4.0	4.8 - 13.0
A3	0.0 - 1.4	0.0 - 4.8

<u>Netherlands</u> NEN 3661 Window frames, air permeability, water tightness, rigidity and strength. (Gevelvullingen Luchtdoorlatendheid, Waterdichtheid stijfheid en sterkte) Eisen NNI 1988.

The Dutch standard NEN 3661 gives air leakage through cracks in windows, given at two exposure levels, four classes of test pressures and three heights of window. The average leakage rate must not exceed 2.5 dm^3/s per metre length of crack.

Height of building in which the window is located (m)	Exposure	Pressure difference (Pa)	Air Leakage (dm3/(m.s)
15	Normal	150	3.5
40	Normal	200	3.0
100	Normal	300	2.5
15	Coastal	300	2.5
40	Coastal	300	2.5
100	Coastal	450	2.5

A further requirement to the above is that the local air leakage along any 100 mm section of frame, should not exceed 0.5 dm^3/s at the prescribed test pressures.

New Zealand NZS 4211:1987. Specification for performance of windows. Standards Association of New Zealand.

New Zealand has few airtightness and ventilation rate standards. Windows for domestic buildings must pass an air leakage test set out in NZS N4211:1987. This standard classifies windows into three categories according to air leakage performance, and gives maximum rates of leakage at 150 Pa for each level.These are given below:

	Rate of air leakage (dm3/s) 1	2	3
Per m of opening joint length	0.6	2.0	4.0
Per m2 of total window area	2.0	8.0	17.0

Notes:
1 Airtight.
2 Moderate air leakage.
3 Low air leakage resistance.
1 Tested for both inwards and outward leakage.
2 and 3 Tested for inward air leakage only.

Switzerland SIA 331 Windows, Fenster.

In this standard upper limits for the leakage of windows are given. In recent additions to this standard only one value for Q-value (termed a-value in standard) used (0.2 m^3/h.m where n=2/3rds or 0.66)

Window group	A	B	C
Pressure in test (Pa)	150	300	600
Building height (m)	0..8	>8..20	>20..100
Requirements:			
Allowable volume flow rate at given pressures (m3/h.m)	5.65	8.95	14.25
To work backwards to obtain volume flow rate assume Q to equal (m3/h.m Pa 2/3rds[0.66])	0.2	0.2	0.2

New windows can easily be 10 times tighter than this prescribed value; [0.2 m^3/h. m at Pa 2/3rds] and thus in many cases this prohibits basic ventilation.

United Kingdom

BSI 6375:1983 Performance of windows. PT 1, Classification of weathertightness.

The British Standard: BSI 6375:1989 classifies airtightness according to exposure, and is applicable to all window types in which any frame member is not longer than 3 m, including adjustable louvers and sliding windows.

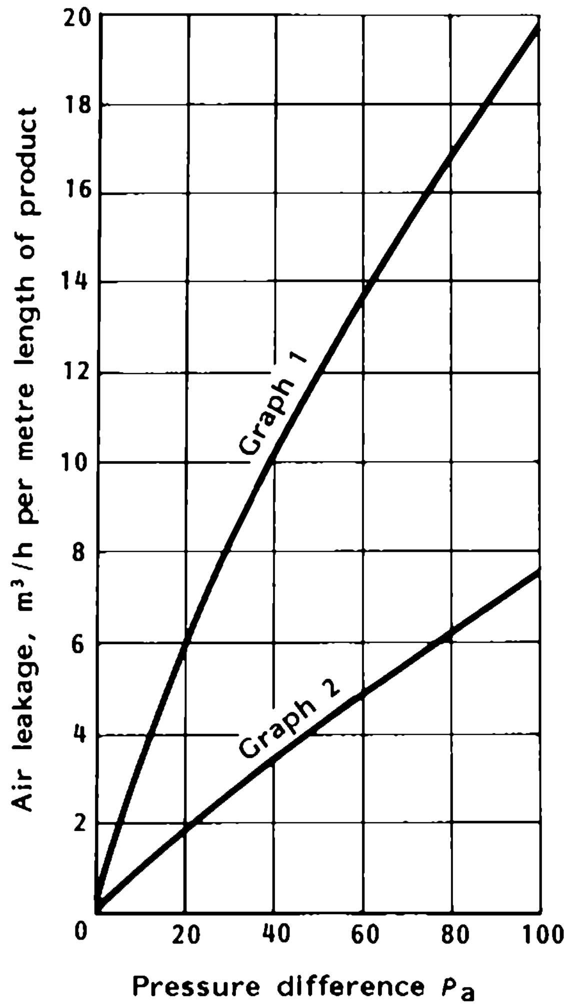
The standard gives air permeability limits for windows, between the limits of window category A & B, where respective K values are; KA = 0.4678 & KB = 0.357, and where n=0.66. Values for a third category of window are also stated, for air conditioned Buildings, type C, in this case KC = 0.0928. The air leakage values are outlined below:

Therefore allowable air leakage at test pressure of 50 Pa (m3/h.m)	TO	Allowable air leakage last test pressure (m3/h.m)
A = 6.3	TO	200 Pa A = 15.40
B = 4.8	TO	300 Pa B = 15.40
C = 1.22	TO	600 Pa C = 6.6

BS7396:1990 Specification for: Draughtstrips for the draught control of existing doors and windows in housing (including test methods).

This standard specifies the maximum air leakage through a product as follows:

When tested by the methods described in A.7 and when installed in the maximum gap size specified, and compressed/deflected in accordance with the product information, products designed to fit a maximum gap size of 10mm shall comply with line (a); those designed to fit a maximum gap size greater than 10mm shall comply with line (b).



NOTE: Graph 1: products designed to fit maximum gap size of 10 mm or less. Graph 2: products designed to fit maximum gap size greater than 10mm.

United States of America

ASHRAE 90.1-80. Energy conservation in new building design. Non residential
ASHRAE 90.2-80. Energy conservation in new building design. residential

The American ASHRAE Standard 90-80 gives recommendations for the leakage rate of windows at 75 Pa pressure difference as no more than 0.77 dm^3/s per metre of sash (2.772 $m^3/h.m$ of sash).

A.1.2.2 Doors

Belgium, Canada, Denmark, France and the United States of America are the only countries to have specific airtightness standards for doors.

Belgium

In Belgium, STS 53.04 gives requirements regarding the airtightness of doors. The requirements for doors apply for all construction works where the requirements of STS 53.0 must be met: This is in practice all governmental buildings and social dwellings.

Airtightness Class	Pressure Difference	Single Door	Double Door
A	10 Pa	<20 m3/h	<40 m3.h
B	50 Pa		

Canada

NRCC No. 22432 Measures for energy conservation in new buildings. Associate Committee of the National Building Code. National Research Council of Canada 1983.

CGSB 82-GP-2m (1977) Doors, Glass, Aluminum Frame, Sliding, Medium-Duty.

The Canadian standard "Measures for energy conservation in new buildings" - 1983 states that manually operated exterior sliding glass doors shall conform to the air leakage requirements set out in CGSB 82-GP-2m (1977) "Doors glass aluminum frame sliding medium duty." and shall be designed to limit the rate of air leakage to not more than 2.54 l/s for each square metre of door area when tested to ASTM E283-73 "Standard test method for rate of air leakage through exterior windows curtain walls and doors". In addition those doors with high energy requirements must protect exterior doors with a enclosed vestibule and shall be equipped with self closing devices.

Denmark

DK-418 Beregning af bygningers varmetab. 1977.

0.50 $dm^3/s.m$ at 50 Pa length of crack.

France French Standard NF P 20-302 applies to windows, but is also used for doors. (See Windows section A.1.2.1).

United States of America

ASHRAE 90.1-80 Energy Conservation in New Building Design. non residential

ASHRAE 90.2-80 Energy Conservation in New Building Design. residential

The United States air leakage requirements for doors are set out in "ASHRAE Standard 90-80" and are outlined below:

Door type	Maximum air leakage rates at a pressure difference of 75 Pa
Sliding glass doors (residential)	2.5 dm3/s per m2 of door area
Entrance swinging doors (residential)	6.35 dm3/s per m2 of door area
Swinging, revolving sliding doors for other than residential use.	17.0 dm3/s per linear metre of door crack

These criteria are similar to those of Canada.

A 1.2.3 Other Components

Netherlands Dutch legal requirement for floor directly above crawl space is 20E -6 $m^3/m^2.s$ at 1 Pa Ref: Mentioned in Building Decree 16th Dec. 1991, p20: (NEN 2690).

France In order to calculate ventilation heat losses, French Building Regulations, according to DTU Regles ThG April 1991, stipulate that the air leakage rate of opaque external walls of the dwellings is:

single family dwellings: 0.5 $m^3/h.m^2$ for $\Delta P = 1$ Pa.
multifamily dwellings: 0.25 $m^3/h.m^2$ for $\Delta P = 1$ Pa.
The values are given for $1 m^2$ of dwelling surface area.

A.1.2.4 Techniques for measuring air leakage

A.1.2.4.1 Techniques for Measuring Air Leakage of Whole Buildings

Canada Determination of Airtightness of Buildings by the Fan Depressurisation Method.CAN2-149.10-M86

France — Test method for determining airtightness of residential buildings.

(Guide méthodologique pour la mesure de la perméabilité à l'air des enveloppes de bâtiments) Cahiers du CSTB No. 2493. 1991.

ISO — DP 9972 Measurement of building airtightness using fan pressurisation. Draft Proposal.

Netherlands — NEN 2686 Air leakage of buildings - Method of measurement. (Luchtdoorlatendheid van gebouwen Meetmethode) NNI 1988.

Norway — NS-INSTA 130 Airtightness of buildings. Test method. (Bygningers lufttetthet. Provingsmetode) NSF 1981

Sweden — SS02 15 51 Buildings - Determination of airtightness. 1987.

NT VVS 019 Method of determining the local mean age of ventilation air in buildings. 1986.

United Kingdom

Determining air tightness of buildings by the fan pressurisation method: BRE recommended procedure.

United States of America

ASTM E779-91 Standard test method for determining air leakage rate by fan pressurisation.

A.1.2.4.2 Techniques for Measuring air Leakage of Building Components.

Belgium — STS 52.0 Menuiseries Exterieures - Generalities.

NBN B25-204 (EN42): Methods of testing windows. Part 1 : Air Permeability tests, 1981.

NBN B25-205 (EN77): Methods of testing windows. Part 2 : Wind resistance tests, 1981.

NBN B25-206 (EN78) : Methods of testing windows. Part 3: Form of test report, 1981.

NBN B25-209 (EN86) : Methods of testing windows. Part 4 : Water tightness test under static pressure, 1981.

NBN B25-210 (EN107) : Methods of testing windows. Part 5 : Mechanical tests, 1982.

Denmark DS/EN42 Methods of testing windows. Air permeability test (Vinduesprovning Luftaehed). 1976.

ECl European Standard EN42 Method of testing Windows; Air permeability

France Methods of testing windows. (Methodes d'essais des fenetres)French Standard NF P 20 501 July 1974.

Germany DIN 180 55. Windows. Air permeability of joints, water tightness and mechanical strain, requirements and testing. (Fenster. Fugendurchlassigkeit, Schlargegendichtheit und mechanische Beanspruchung Anforderungen und Prufung). October 1981.

DIN (EN42) Methods of testing windows. Part 1: Air permeability tests, 1981.

DIN (EN77) Methods of testing windows. Part 2: Wind resistance tests, 1981.

DIN (EN78) Methods of testing windows. Part 3: Form of test report, 1981.

DIN (EN86) Methods of testing windows. Part 4: Water tightness test under static pressure. 1981.

DIN (EN107) Methods of testing windows. Part 1: Mechanical tests, 1982.

International Standards Organisation (ISO)

ISO 6613-1980(E) Windows and door height windows - Air permeability. 1980.

ISO 6589-1981 Joints in building - Method of test for air permeability of joints. 1981.

Italy UNI 7357 Calculation of heat requirements for building heating.

Ministrial Decree 05.07.75 Ventilation requirements for residential buildings.

Ministerial Decree 02.02.76 Ventilation requirements for schools.

Netherlands NEN 3660 Window frames - Air permeability, rigidity and strength. Methods of test. NNI 1988

New Zealand NZS 4211:1987 Specification for performance of windows. Standards Association of New Zealand.

Norway NS3206 Methods of testing windows. Airtightness. NSF 1974.

Sweden SS02 I5 51 Buildings - Determination of airtightness. 1987.

United Kingdom

BS 5368 PT 1:1976 Methods of testing windows. Part 1. Air permeability test.

United States of America

ASTM E783-91 Field testing for leakage of doors and windows. ASTM E283-91 Laboratory testing for doors windows and curtain walls

A.2 Minimum ventilation rates

All AIVC countries have recommended values for minimum ventilation rates for dwellings, and most also have recommended values for industrial/commercial building types.

A.2.1 Minimum ventilation rates standards for dwellings

<u>Belgium</u> NBN D50 -001 : Ventilation systems for housing. October 1991.

The basic principle is 1 l/s per m^2 of floor area with some specific values for kitchen, toilet and bathroom.

<u>Canada</u> CSA Preliminary Standard F326.1-M1989 Residential Mechanical Ventilation Requirements.

0.3 ach or 5.0 l/s per person (for mechanical system to each inhabitable room)

Kitchen exhaust - intermittent 50 l/s Kitchen exhaust - continuous 30 l/s
Bathroom exhaust - intermittent 25 l/s Bathroom exhaust - continuous 15 l/s

American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) 62-1989 Ventilation for acceptable indoor air quality.

Outdoor air requirements for ventilation of residential facilities.

Whole buildings 0.35 ACH but no less than 7.5 l/s per person.

Kitchen : 50 l/s intermittent OR 12 l/s continuous OR operatable windows.
Bathroom : 25 l/s intermittent OR 10 l/s continuous OR operatable windows.

Intermittent and Continuous refer to installed mechanical capacity.

<u>Denmark</u> DS 418 Calculations of heat loss from buildings. 1977.

Tight living rooms: 0.4 ach Normal living rooms: 0.6 ach
kitchens and bathrooms: 0.7 ach

<u>Finland</u> D2 - Indoor climate and ventilation in buildings.Regulations and Guidelines. National Building code of Finland. The Ministry of the Environment.

Bedrooms minimum air flow rate of (4.0 dm^3/s.person) 4.0 l/s per person or (0.7 $dm^3/s/m^2$ of floor area) 0.7 l/s m^2 floor area

Living rooms: 0.5 l/s m^2
Kitchen Exhaust air flow :20 l/s
Bathroom exhaust air flow: 15 l/s

These exhaust air flows can be reduced when the spaces are not in use provided that the air change rate in the whole building is greater than 0.4 ach and minimum air flow rates in bedrooms and living rooms are fulfilled.

France

French regulations for ventilation of dwellings.

Kitchens continuous: 20 - 45 m^3/h intermittent: 75-135 m^3/h
Bathrooms with WC :15-30 m^3/h
WC only: 15-30 m^3/h

Germany

DIN 18017 Ventilation in bathrooms and WC's without outside windows by fans, amendment 1. April 1988.

Part 1. Ventilation of bathrooms and WC's without outside windows; single shaft systems without ventilators. Feb. 1987

Part 3. Ventilation of bathrooms and WC's without outside windows; with ventilators.

Part 4. Ventilation of bathrooms and wash-down closets without outside windows with ventilators; rules for the calculation of the airflow requirements.

DIN 1946 Pt. 6. Ventilation and airconditioning ventilation for residential buildings; Requirements, performance and testing. (VDI ventilation rules)(draft November 1989)

Dwelling Group	Dwelling Space	Number of Occupants	Ventilation Rate (m3/h) Min	Total
1	<50	upto 2	60	60
2	<80	upto 4	90	120
3	>80	upto 6	120	180

The above table gives ventilation rates in rooms with windows.

Dwelling Rooms	Airflow when Occupied for more than 12 hours per day. (m3/h)	Overall Airflow (m3/h)
Kitchen (Normal)	40	60
Kitchen (Purge)	200	200
Kitchen-et	40	60
Bathroom (with WC)	40	60
WC	20	30

The above table gives recommended ventilation rates for rooms in dwellings which do not have windows.

VDI 2088 - Ventilating of dwellings - 1976

Living rooms :1.0 to 1.5 ach Bathrooms and toilets: 6.0 ach Kitchens (exhaust ventilation): 120 m^3/h Internal bathrooms (exhaust ventilation): 60 m^3/h Internal toilet (exhaust ventilation): $30m^3/h$

<u>Italy</u> Ministerial Decree 05.07.75 Ventilation requirements for residential buildings.

Naturally ventilated Dwellings: 0.35ach to 0.5ach Kitchens : 1.0 ach Bathrooms: 2.0 ach Ante-bathrooms : 1.0 ach Normal living spaces (living rooms etc.,) :15 m^3/h per person

<u>Netherlands</u> NEN 1087 - Ventilation in dwellings. Requirements. NNI 1991

7 dm^3/s person (NEN 1087) Guidelines covering new laws are being produced especially in relation to the standard on the requirements for the ventilation of dwellings.

Bedrooms: 1 $dm^3/s.m^2$ of floor area
Living rooms: 1 $dm^3/s.m^2$ of floor area Kitchen : 21 dm^3/s
Bathroom with WC: 14 dm^3/s WC only: 7 dm^3/s

<u>New Zealand</u> American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) 62-1989 Ventilation for acceptable indoor air quality.

Outdoor air requirements for ventilation of residential facilities.

Whole buildings 0.35 ACH but no less than 7.5 l/s per person.

Kitchen : 50 l/s intermittent OR 12 l/s continuous OR operatable windows.
Bathroom : 25 l/s intermittent OR 10 l/s continuous OR operatable windows.

Intermittent and Continuous refer to installed mechanical capacity.

New Zealand have adopted the ASHRAE 62-1989 standard.

Ventilation requirements for domestic buildings are mentioned in chapter 4 of NZS 1900, no ventilation rates are specified directly but gives a minimum area of openable window as 5 % of the floor area in each room.

<u>Norway</u> Norwegian Building Code Chapter 47, Ventilation and installation. 1987. The Norwegian Building Code gives requirements for minimum ventilation rates expressed in either minimum sectional area of ventilation ducts from different rooms when using natural ventilation,or a specified air flow rate for rooms with mechanical ventilation.

Room in Dwelling	Exhaust air Cross-section of duct (cm2)
Living rooms (Including Bedrooms)	Supply Air: Openable windows or inlet bigger than 100cm2 in external wall
Kitchen and Bathrooms	Extract Air: Mechanical Extract of 60m3/h 17 l/s or Natural Extract: at least 150 cm2 duct above roof.
WC Only	Extract Air: Mechanical 40 m3/h (11 l/s)or Natural 100cm2/duct above roof.

<u>Sweden</u> BFS 1988:18 Chapter 4:1 Air Exchange. National Board of Housing Building and Planning.

Outdoor air flow to rooms with normal ceiling height occupied by persons on more than a temporary basis shall be at least 0.35 l/s of floor area (per m^2)

Applies to entire apartments as well as individual rooms for dwellings.

Bedrooms:4.0l/s per person Kitchens :10.0 l/s and forced with at least 75% capture area by the air device. Bathroom (With openable window): 10.0 l/s Bathroom (Without openable window): forced to 30 l/s or 15l/s constant.

<u>Switzerland</u> SIA 384/2 Heating load calculations.1980.

This recommendation deals with heat loss calculations and gives some procedures how to determine the ventilation losses. The air flows mentioned cannot directly be interpreted as minimum ventilation requirements, but are commonly cited due to lack of other Swiss standards.

SIA 382/1. Ventilation and AC Plants, technical requirements. 1992.

The airflows to be assumed are :

The natural in/exfiltration flows through windows and other component leakages, according to the procedure given in recommendation. The lower limit (minimum ventilation rates) is either:

0.3 ACH or 13.0 m^3/h (non-smoker) 20.0 m^3/h (smokers)

For rooms with mechanical extract 1 hour peak and 24 hour mean air flow are given from SIA 382/1 1992

United Kingdom

British Standard BS5720 - 1979 - Code of Practice for mechanical ventilation and air conditioning in buildings.

British Standard BS5925: 1991 - Code of Practice for ventilation principles and designing for natural ventilation.

CIBSE - Guide A - Design Data.CH 1 - Environmental Criteria for design. The Chartered Institute of Building Services Engineers. Delta House, Balham High Road, London.

Both of these standards and the CIBSE guide give the following recommended and minimum ventilation rates for residences.

	Ventilation Rate (l/s.person) Recommended	Minimum
Average Dwelling	12.0	8.0
Luxury Dwelling	18.0	12.0

United Kingdom Building Regulations Part F 1985. Revised 1990. Ventilation. F1 Means of ventilation. Pub. The Department of the Environment

The requirement of this building code is that there shall be adequate means of ventilation provided for people in the building. Applying to dwellings, spaces in any building containing two or more dwellings which are used solely or principally with those dwellings, bathrooms and rooms containing sanitary conveniences.

A) Ventilation of habitable rooms. (excluding bathrooms)

Rapid ventilation: one or more ventilation openings with a total area or at least 1/20th of the floor area of the room, and with some part of the ventilation opening at least 1.75m above the floor level, e.g. an opening window and

Background Ventilation: a ventilation opening(s) having a total area not less than 4000 square millimetres or a trickle ventilator. The opening(s) should be controllable and secure and located so as to avoid undue draughts.

Two habitable rooms may be treated as a single room for ventilation purposes if there is an area of permanent opening between them equal to at least 1/20th of the combined floor areas.

A habitable room may be ventilated through an adjoining space if: 1. the adjoining space is a conservatory or similar space and
- there is an opening (which may be closable)between the room and the space with an area not less than 1/20th of the combined floor areas of the room and space and
- there are one or more ventilation openings with a total of at least 1/20th of the combined floor area of the room and space and with some part of the ventilation opening at least 1.75m above the floor level and
- for background ventilation there are ventilation openings to the space and openings between room and space, each having a total area not less than 4000 square millimetres. The openings should be located so as to avoid undue draughts.

B) Ventilation of Kitchens

The requirement shall be satisfied is there is both:

- mechanical extract ventilation for rapid ventilation, rated as capable of extracting at a rate not less than 60 l/s (or incorporated within a cooker hood and capable of extracting at a rate of 30 l/s) which may be operated intermittently for instance during cooking and

- background ventilation either: a) by controllable and secure ventilation opening(s) having a total area not less than 4000 square millimetres, located so as to avoid draughts eg a trickle ventilator.

b) by the mechanical ventilation being in addition capable of operating continuously at nominally 1 ach.

C) Ventilation of common spaces containing two or more dwellings.

The requirement shall be satisfied if there is provision for ventilation by ventilation opening(s) with a total area of at least 1/50th of the floor area of the common space or communicating common spaces.

Where the space is wholly internal and is used for access only the requirement can also be satisfied by the provision of mechanical extract ventilation capable of 1 ach.

D) Ventilation of bathrooms.

The requirement shall be satisfied by the provision of mechanical extract ventilation at a rate not less than 10 l/s which may be operated intermittently.

E) Ventilation of Sanitary accommodation.

either

- rapid ventilation by one or more ventilation openings with a total area of at least 1/20th of the floor area of the room, and with some part of the ventilation opening at least 1.74 metres above the floor level;

OR

- mechanical extract ventilation capable of extracting air at a rate not less than 3 ach, which may be operated intermittently with 15 minutes overrun.

United States of America

American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) 62-1989 Ventilation for acceptable indoor air quality.

Outdoor air requirements for ventilation of residential facilities.

Whole buildings 0.35 ACH but no less than 7.5 l/s per person.

Kitchen : 50 l/s intermittent OR 12 l/s continuous OR operatable windows.
Bathroom : 25 l/s intermittent OR 10 l/s continuous OR operatable windows.

Intermittent and Continuous refer to installed mechanical capacity.

A.2.2 Minimum Ventilation Requirements for Office and School Buildings

Belgium NBN B 62-003 Heat loss calculations. (Calcul des deperdition calorifiques)

The scope of this standard is the sizing of heating elements. Information about the air flow rates to be taken into account are given : $10 m^3/h$ per person (non-smoking) and $20 m^3/h$ per person (smoking). These values assume that $10 m^3/h$ per person of outdoor air can be heated up by the metabolism of each occupant.

There is also a general requirement for the ventilation of workplaces. This value is $30 m^3/h$ per person.

Canada NRCC No. 22432. Measures for energy conservation in New Buildings. Associate Committee on the National Building Code. National Research Council of Canada. No. 22432 Ottawa. 1983.

Measures for energy conservation in new buildings sets out the requirements for mechanical ventilation - where the outdoor air supply will be in line with those stated in ASHRAE 62-1989: 8 to 30 l/s per person for commercial and factory buildings.

The are no provisions in the Canadian or provincial building codes on ventilation for schools. Most schools are owned and operated by local boards. Many of these boards follow the ASHRAE 62-1989 standard, but this is not consistent or universal. - Communication from Mr I Morrison.

8 l/s per person.

<u>Denmark</u> Danish Building Regulations (Bygningsreglement 1982), Ministry of Housing, Copenhagen. 1982.

This standard specifies 4 to 10 l/s per person. The values are based on removal of pollutants, where smoking is allowed they recommend high ventilation rate of 10 l/s per person, independent of room size. Where smoking is not allowed, the ventilation rate per person decreases as the room volume increases.

<u>Finland</u> Indoor Climate and Ventilation in Buildings. Regulations and Guidelines. Guidelines 1985. National Building Code of Finland. (In Finnish).

This standard also specifies 4 - 10 l/s per person. The values are based on removal of pollutants. Where smoking is allowed they recommend a high ventilation rate of 10 l/s per person, independent of room size. Where smoking is not allowed, the ventilation rate per person decreases as the room volume increases.

D2 - National Building Code of Finland:Indoor climate and ventilation in buildings. Regs and guidelines - 1987.

Classroom : Outdoor air supply rate of 6 dm^3/s person. Lecture room : Outdoor air supply rate of 8 dm^3/s persons.

<u>France</u> Practical guidance to meeting the requirements of the Thermal and Ventilation Regulations for Non residential Buildings - Cahiers du CSTB No. 2286 - October 1988. (Exemples de solutions pour facliter l'application du reglement relatif aux équipements et aux caractéristiques thermiques dans le bâtiments autres que l'habitation. VENTILATION).

This document indicates minimum and maximum ventilation rates for different kinds of non residential premises, particularly for schools and buildings designed for teaching and for office buildings.

Requirements: The minimum ventilation rates are a function of the types of premises and are indicated in the charts here enclosed. For current teaching rooms the required value of fresh air is 15 m^3/h per person. For current offices it is 25 m^3/h per person and for meeting rooms 18 m^3/h person (non-smoking) or 30 m^3/h per person (Smoking).

The maximum ventilation rate is 1.2 (for cold climatic zones) or 1.3 (For temperate climatic zone) times the minimum ventilation rate.

Germany

DIN 1946 Part 2. Room ventilation technique; Technical health principles (VDI ventilation rules). (1983)

DIN 1946 gives a general air flow rate for indoor air quality of 20 to 30 m^3/h person to maintain acceptable air quality.

The standard gives minimum ventilation rates for schools as 30 m^3/h per person.

Italy

Ministerial Decree 04.02.76 Ventilation requirements for schools.

1.5 to 5 ach for school buildings.

Netherlands

NPR 1019. Ventilation in school buildings.

The fresh air requirements in schools of 5.5 dm^3/s per pupil is the minimum ventilation rate which approximates to a carbon dioxide concentration of 1200 ppm.

Cox C W J (1990), Standards and guidelines for indoor air quality. Normen en richtlijnen voor het binnenmilieu. Netherlands, Klimaatbeheersing, Vol 19, No 6, June 1990, pp 172-177, 9 refs.#DATE 00:06:1990 in Dutch (#NO 4573)

Office: 35 m^3/h outside air per person if there is no smoking allowed.

55 to 60 m3/h per person if smoking is allowed.

ASHRAE 62-1989 gives:

General office space: 35 m^3/h per person Smoking 100 m^3/h per person.

New Zealand

New Zealand has adopted the ASHRAE 62-1989 standard - Ventilation for acceptable indoor air quality.

Offices : minimum 10 l/s.person, whether smoking is permitted or not. (Note design occupancy)

In smoking lounges : 30 l/s.person.

In schools : 8 l/s.person

Norway

NS3031 Energy and power demands for heating of buildings. Calculation rules.

For other than domestic buildings the ventilation requirements are given as air flow rate per unit floor area. NS3031 gives an assumed air change rate of 0.5 ach for a building when calculating ventilation heat loss.

Work rooms 5 m^3/h. m2 or 16.5 m^3/h per person Offices 7 l/s plus 0.7 l/s.m^2 floor area

Schools

Norwegian National Building Code: Ventilation and Installation.

Minimum ventilation rates for classrooms: 5.5 l/s per person plus 0.7 l/s. m^2.

Sweden

Standard BFS Chapter 4:1. Air Exchange. National Board of Housing Building and Planning.

Extract from Standard BFS 4:1 Rooms for sedentary work: 5.0 l/s per person Rooms for mobile work : 7.0 l/s per person Rooms where smoking is permitted : 10.0 l/s per person

Schools same as offices.

Switzerland

SIA 382/1. Ventilation and AC Plants, technical requirements. 1992.

This standards recommends outside air rates per person [m^3/hr. Pa]

Zone Type	Air Quality Level	Air Flow Rate (m3/h)
Non-Smoking	0.15% CO2 0.10% CO2	v=12-15 m3/h.person v=25-30 m3/h.person
Smoking		v=30-70 m3/h.person

Note there is no special distinction between schools and offices.

For non-occupied rooms : 0.3 ach or pre-ventilation is recommended.

United Kingdom

Workplaces

British Standard BS5720 - 1979 - Code of Practice for Mechanical Ventilation and Air Conditioning in Buildings.

British Standard BS5925: 1991 - Code of Practice for Ventilation principles and designing for natural ventilation.

Work Place	Smoking	Recommended (l/s per person)	Minimum
Factories	None	8	5
Offices (open plan)	Some	8	5
Offices (Private)	Heavy	12	8
Laboratories	Some	12	8
Conference Rooms	Some	18	12
Board Rooms, executive offices and conference rooms	Very Heavy	25	18

Recommended levels: 8 - 25 l/s person
Minimum Levels: 5 - 18 l/s per person

Guidance Note EH 22 from the Health and Safety Executive. Ventilation of the workplace. (Revise may 1988)

Respiration: A person's need for fresh air depends on his metabolism, or rate of activity. On average 0.5 l/s per person of fresh air will be required to provide sufficient oxygen for respiration but this can range from 0.15 to 1.0 l/s for heavy work. Approximately 2 l/s per person will be required to dilute exhaled carbon dioxide to the occupational exposure limit 0.5%.

Odour: Requirements depend largely on space available per person, personal cleanliness and personal sensitivity. Odour is unlikely to be a problem at ventilation rates of 9.0 l/s per person.

Tobacco Smoke: The Chartered Institution of Building Services Engineers (CIBSE) recommends air supply rates ranging from 16 l/s person where there is some smoking to 32 l/s person for very heavy smoking.

The fresh air supply rate to a workplace should not fall below 5l/s person. Higher rates are recommended especially if some or all of the occupants smoke.

According to this publication the rates specified in the above table (taken from BS5925; BS5720 and the CIBSE Guide A1) may be used as a general guide to requirements for non air conditioned spaces.

Smoking in Public Places: Guidance for owners and managers of places visited by the public. Code of Practice. Pub. Dept. of the Environment.p7

A ventilation rate of 8 l/s per person ($30m^3/h$) of outdoor air is usually adequate for non smoking rooms. But where smoking is allowed this rate must be three to four times greater to avoid acute irritating effects even in healthy people.

Air contaminated with tobacco should not be recirculated, separate smoking rooms set up in air conditioned buildings for example should be separately vented to the outside.

Workplace health, safety and welfare. Approved code of practice. Health and safety commission. 1992.

Regulation 6. Ventilation. This regulation covers general workplace ventilation not exhaust ventilation for controlling employees' exposure to asbestos, lead, ionising radiations of other substances hazardous to health. See COSHH requirements.

States that fresh air supply rate shall not be allowed to fall below 5 to 8 l/s per person. Factors to be considered include floor area per person, the processes and equipment involved and whether the work is strenuous. For more guidance see CIBSE publications.

Schools:

The Chartered Institution of Building Services Engineers (CIBSE) Guide A4 - 14 Air Infiltration.

Empirical values for air infiltration and ventilation allowance for buildings on normal sites in winter:

Schools:

Classrooms	2 ach
Lecture rooms	1 ach

The Chartered Institution of Building Services Engineers (CIBSE) Guide B2 - 7 Ventilation and Air Conditioning (Requirements) From table: B2.3 Ventilation requirements.

Schools' recommended fresh air supply rate : that working areas should be capable of being ventilated at least up to 8.3 l/s per person.

United States of America

ASHRAE 62-1989. Ventilation for acceptable indoor air quality.

Offices : minimum 10 l/s.person, whether smoking is permitted or not. (Note design occupancy)

In Smoking lounges : 30 l/s.person.

In schools : 8 l/s.person

Concentration Level Country	MAC ppm	Peak limit ppm	Ref.	ME-value ppm	Ref.	AIC ppm (absolute)	Ref.	Remarks 1 ppm = 1.806 mg/m³ (at 1 bar, 293 K)
Canada	5000 -	-	21	-		3500 1000	22 20	CO_2 level not used as indicator for body odour Produced by metabolism
Germany	5000	2 x MAC	8	-		1000 1500 max.	24 24	Pettenkofer-value used to establish necessary AIC-air flow rates
Finland	5000	5000 (15 min)	1	-		2500	35	AIC: of which 1500 ppm is produced by metabolism If the outdoor air flows are controlled based on the carbon dioxide content of the indoor air, a maximum set point of 800 ppm may be used
Italy	-	-		-		1500	2	
The Netherlands	5000	15000 short time	40 41	-		1000-1500	42	
Norway	5000	MAC + 25% (15 min)	3	-		-		
Sweden	5000	10000	4	-		-		supply air 1/10 of MAC /5/
Switzerland	5000	-	6	-		1000-1500	30	proposed according /30/
U.K.	5000	15000 (10 min)	17	-		-		
U.S.A.	5000	-	21	-		1000	20	
Columbus Space station	-	-	-	-		4000	19	

MAC = Maximum Allowable Concentration at the work space 8 h/d
ME-value = Maximum Environmental Value
AIC = Acceptable Indoor Concentration

Threshold levels for carbon dioxide (CO_2) in different countries

Concentration Level Country	MAC ppm	Peak limit ppm	Ref.	ME-value ppm	Ref.	AIC ppm	Ref.	Remarks 1 ppm = 1.231 mg/m³ (at 1 bar, 293 K)
Canada	1	2 (15 min)	21	-		0.1 0.1	20 22	
Germany	1	2xMAC, 5 min average	8	-		0.1	14	
Finland	-	1 (15 min)	1	-		0.12 0.24	11	AIC: for new buildings for existing buildings
Italy	-	-		-		-		
The Netherlands	1	2 (15 min)	40	-		0.1(0,5h)	43	
Norway	1	+100% (15 min)	3	-		-		
Sweden	0.5	1 (15 min)	4	-		0.1 0.01-0.05	5,10 12	supply air 1/10 of MAC, safety factor 10 AIC-safety factor for avoiding annoyance: 10 /5/
Switzerland	1.0	-	6	-		0.2	13	
U.K.	2	2 (10 min)	17	-		-		
U.S.A	1	2 (15 min)	21	-		0.1	20	
WHO		-		-		0.1 0.08	10 10	AIC: Guideline value based on effects other than cancer or odour/annoyance

MAC = Maximum Allowable Concentration at the work space 8 h/d
ME-value = Maximum Environmental Value
AIC = Acceptable Indoor Concentration

Maximum concentration level for formaldehyde (HCHO) in buildings in different countries

Concentration Level / Country	MAC ppm	Peak limit ppm	Ref.	ME-value ppm	Ref.	AIC ppm	Ref.	Remarks 1 ppm = 1.888 mg/m³ (at 1 bar, 293 K)
Canada	3	5 (15 min)	21	-		0.3 0.052	20 22	offices homes
Germany	5	2xMAC (5 min average)	8	0.1 (1/2 h) 0.05(24 h)	9	-	35	
Finland	3	5 (15 min)	1	-		0.08 daily av. 0.16 hourly av.	35	
Italy	-	-		-				
The Netherlands	2	-	40	-		0.16 (1 h) 0.08 (24 h)	43 43	
Norway	-	-		-		-		
Sweden	2	5, 15 min	4	-		0.2 0.15	12 10	supply air 1/10 of MAC, max. value for 24 h /5/
Switzerland	3	-	6	0.04 (24h) a) 0.05 b) 0.015 c)	16 + 37	d)		a) 24 h mean value ought to be exceeded only once a year b) 95 % of 1/2 h mean values of a year ≤ 0.05 ppm c) annual arithmetic mean d) there are no building regulations for kitchens with gas-powered furnaces
U.K.	3	5 (10 min)	17	-		-		
U.S.A	3	5 (15 min)	21	-		0.3	20	offices
WHO				0.16	10	0.21 1 hour 0.08 24 hour		AIC: Guideline value, based on effects other than cancer or odour/annoyance

MAC = Maximum Allowable Concentration at the work space 8 h/d

ME-value = Maximum Environmental Value

AIC = Acceptable Indoor Concentration

Maximum concentration level for nitrogen dioxide (NO_2) in buildings in different countries

Concentration Level Country	MAC ppm	Peak limit ppm	Ref.	ME-value ppm	Ref.	AIC ppm	Ref.	Remarks 1 ppm = 1.149 mg/m³ (at 1 bar, 293 K)
Canada	50	400 (15 min)	21	-		9	20.22	
Germany	30	2 x MAC (30 min) average	8	43 (1/2 h) 8 (24 h) 8 (1 year)	9	1-2 9 living rooms 18 kitchen (3 h)	7 27 27	
Finland	30	75 (15 min)	1	-		8.7 daily av. 26 hourly av.	35	
Italy	30	-	2	-		-		
The Netherlands	25	120 (15 min)	40	-		35 (1 h) 8.7 (8 h)	43	
Norway	35	+50% (15 min)	3	-		-		
Sweden	35	100	4	-		12	10	supply air 1/10 of MAC /5/
Switzerland	30	-	6	7 (24 h) average	16 37	-	-	ME-value: this value ought to be exceeded only once a year
U.K.	50	400 (10 min)	17	-		-		
U.S.A	50	400 (15 min)	20			9	20	
WHO		87 (15 min) 53 (30 min) 26 (1 hour) 9 (8 hours)	10	-		-		Guideline value; based on effects other than cancer or odour/annoyance
Airplanes	50	-	18	-		-		

MAC = Maximum Allowable Concentration at the work space 8 h/d
ME-value = Maximum Environmental Value
AIC = Acceptable Indoor Concentration

Maximum concentration level for carbon monoxide (CO) in buildings in different countries

Annex 18 References for the previous four tables. {Taken from IEA Annex Raatschen (ed) Demand Controlled Ventilation Systems: State of the Art Review.IEA Annex 18. pp 21, 23, 25, 27.

Ref 1. Air impurities in work place air, Safety bulletin, 3. National Board of Labour Protection, 1981.

Ref 2. Emilia-Romaggna Regional Technical Code, Ed. Franco Angeli. Milano.

Ref 3. Administration normer for forurensning i arbeids ahmosfaeren, 1984.

Ref 4. National Board of Occupational Safety and Health, Sweden. AFS 1987:12, ISBN 91-7930-046-4

Ref 6. Arbeitsplatzsicherheit; Dok. SUVA, 1987.

Ref 8. Maximale Arbeitsplatzkonzentrationen und biologische Arbeitsstofftoleranzwerte 1986, VCH-Verlag, Weinheim.

Ref 10. WHO Guidelines

Ref 17. Guidance Note EH 40"Occupational Exposure Limits", Health and Safety Exectutive" updated annually

Ref 20. ASHRAE Standard 62-1981 R, Ventilation for Acceptable Indoor Air Quality, Table 3, draft, December 15 1987.

Ref 21. TLVs "Threshold Limit Values and Biological Exposure Indices for 1986-87. American Conference of Government Industrial Hygienists, 1986, 6500 Glenway, Cincinnati, Ohio.

Ref 40. N.N De Nationale MAC-lijst 1989, Arbeidsinspectie, p 145, Directoraat-Generaal van de Ardeid.

Additional References

Charlesworth P (1988), Air Exchange Rate and Airtightness Measurement Techniques - An Applications Guide. AIVC 1988.Air Infiltration and Ventilation Centre, University of Warwick Sc. Pk. Coventry, UK.

European Concerted Action (1992), Indoor air quality and its impact on man. Report No. 11. Guidelines for Ventilation Requirements in Buildings.

Liddament M W and Limb M J (1993), An Overview and Rationale of Ventilation related Indoor air Quality Recommendations and Requirements. Proc. Indoor Air 93. 1993. Air Infiltration and Ventilation Centre, University of Warwick Sc. Pk. Coventry, UK.

Raatschen W (ed) (1990), Demand controlled ventilating system - State of the Art Review.IEA Energy Conservation. Air Infiltration and Ventilation Centre, University of Warwick Sc. Pk. Coventry, UK.

NKB (Nordic Committee on Building Regulations: Indoor Climate - Air Quality" NKB Publication no 61 E.

Appendix B Standard Issuing Organisations

Belgium	I.B.N Institut Belge de Normalisation, Avenue de la Brabanconne 29, 1040 Brussels, Belgium (Produce Belgian Standards)
	The National Housing Institute (INL), Unified technical (address as above) (Produce Specifications (STS))
Canada	Associate Committee on the National Building Code National Research Council of Canada, Ottawa, Ontario K1A OR6 (Produce Canadian National Building Code)
	Canadian General Standards Board (CGSB), C\o Dept of Supply and Services 11 Laurier Street, Hull, Quebec K1A OS5 (Produce Canadian Standards)
Denmark	The Danish Standards Association (DS), Aurehojvej 12, DK-2900 Hellerup (Produce Danish Standards)
	Danish Society of Engineers (DIF), Organisation for Norms and Standards, Vester Farimagsgade 31, DK-1606 Copenhagen V (DOF norms, some being published as Danish Standards)
	The Danish Ministry of Housing, National Building Agency, Stormgade 10, DK-1470 Copenhagen K, Denmark (Produce Danish Building Regulations)
Finland	The Ministry of the Environment, PO Box 306, SF 00531 Helsinki 53 (National Building Code)
France	The French Standards Institute (AFNOR), Tour Europe, cedex 7, 92049 Paris La Défense, France (Produce National Standards)
	CSTB, 84 Ave Jean-Jaurès, Champs-sur-marne, 77421 Marne-La-Vallée Cedex 2, France
Germany	The German Standards Institute (DIN), Burggrafenstrasse 4-10, Postfach 1107, 1000 Berlin 30, (Produce German Standards)
	The German Institute of Engineers (VDI), Postfach 1139, 4000 Dusseldorf 1 (Produce Technical Guidelines)
Italy	UNI - ENTE Nazionalle Italiano Di Unificazone, VIA Battistotti Sass 11, 20133 Milano, Italy Tel. +39 2 700241 (Produce National Standards)

Netherlands	The Netherlands Standards Institute (NNI), Kalfjeslaan 2, P O Box 5059, 2600 GB Delft, Netherlands (Produce Dutch Standards)
New Zealand	Standards Association of New Zealand (SANZ), Private Bag, Wellington New Zealand (Produce New Zealand Standards)
	Dept of Health, P O Box 5013, Wellington, New Zealand (Produce The Drainage and Plumbing Regulations 1981)
	Department of Labour, Private Bag, Wellington, New Zealand (Produce The Factories and Commercial Premises Act 1981.)
Norway	Norwegian Standards Association (NSF), Haakon VII's gate 2, Oslo 1, (Produce Norwegian Standards)
	The Norwegian Council for Building Standardisation, Kobenhavngt 10, Oslo 5, (Produce Construction Standards)
	The Royal Ministry of Local Government and Labour, P O Box 8,112 Dep., Oslo 1 (Produce the Norwegian Building Code (BF))
Sweden	Building Standards Institution, Drottning Kristinasvag 73, S-114 28 Stockholm, Sweden (Produce Swedish Building Standards)
	The National Board of Housing, Building and Planning, Box 534, S-371 23 Karlskrona, Sweden (Produce Swedens Building Regulations (NR))
Switzerland	Swiss Standards Association (SNV), Kirchenweg 4, 8032 Zurich, (Produce Swiss Standards)
	Swiss Association of Engineers and Architects (SIA), Postfach 8039, Zurich Switzerland (Produce Swiss Standards on thermal protection and heating ventilation and air conditioning problems)
	Swiss Association of Heating & Cooling Engineers (SWK1), Postfach 2327, 3001 Berne, Switzerland (Produce Recommendations for heating installations, ventilation etc)
United Kingdom	British Standards Institute, Linford Wood, Milton Keynes MK14 6LE (Produce British Standards)
	HMSO Books, P O Box 569, London, SE1 9NH (Produce Building Regulations for England, Wales and Scotland)

United States of America

The American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), 1791 Tullie Circle NE, Atlanta, GA 30329, (Produce HVAC Standards)

American Society for Testing and Materials (ASTM), 1916 Race St, Philadelphia, PA 19103
(Produce Standards on materials, products, systems and services)

US Department of Housing and Urban Development (HUD), 451 Seventh St SW, Washington DC 20410
(Produce Minimum Property Standards)

International Organisations

International Standards Organisation (ISO), 1 rue de Varembe, Case Postale 56, CH 1211 Geneva 20, Switzerland
(Produce International Standards)

European Standardization Committee (CEN), 5 Boulevard de l'Empéreur, B-1000 Brussels, Belgium
(Produce European Standards (EN))

Appendix C - Component Leakage Requirements Normalised to 1 Pa.

Standards, Recommendations and Legal Codes of Practice - Windows

Country/Standard Ref.	Description	Quoted Leakage Value	Leakage at 1 Pa (Flow Exponent assumed 0.66)
Belgium STS 52.0	Building Height 0-10 m	3.00 $m^3.h^{-1}.m^{-1}$ at 100 Pa	0.040 $dm^3.s^{-1}.m^{-1}$
	Building Height 10-18 m	3.00 $m^3.h^{-1}.m^{-1}$ at 100 Pa	0.040 $dm^3.s^{-1}.m^{-1}$
	Building Height >18 m	2.00 $m^3.h^{-1}.m^{-1}$ at 100 Pa	0.027 $dm^3.s^{-1}.m^{-1}$
Canada CAN 3-A440-M84	A1 Low Rise Buildings (<3 storeys, <600 m^2)	2.79 $m^3.h^{-1}.m^{-1}$ at 75 Pa	0.045 $dm^3.s^{-1}.m^{-1}$
	A2 Medium to High Rise Buildings	1.65 $m^3.h^{-1}.m^{-1}$ at 75 Pa	0.027 $dm^3.s^{-1}.m^{-1}$
	A3 High Performance, Institutional &Commercial	0.55 $m^3.h^{-1}.m^{-1}$ at 75 Pa	0.009 $dm^3.s^{-1}.m^{-1}$
	Fixed	0.25 $m^3.h^{-1}m^{-1}$ at 75 Pa	0.004 $dm^3.s^{-1}.m^{-1}$
	Storm (Max)	8.35 $m^3.h^{-1}.m^{-1}$ at 75 Pa	0.134 $dm^3.s^{-1}.m^{-1}$
	Storm (Min)	5.00 $m^3.h^{-1}.m^{-1}$ at 75 Pa	0.080 $dm^3.s^{-1}.m^{-1}$
Denmark DS-418	Assumed Value (When True Value Not Known)	0.50 $dm^3.s^{-1}.m^{-1}$ at 30 Pa	0.053 $dm^3.s^{-1}.m^{-1}$
Finland SFS 3304	Class 1 (Max)	0.50 $m^3.h^{-1}.m^{-2}$ at 50 Pa	0.011 $dm^3.s^{-1}.m^{-2}$
	Class 2 (Min)	0.50 $m^3.h^{-1}.m^{-2}$ at 50 Pa	0.011 $dm^3.s^{-1}.m^{-2}$
	Class 2 (Max)	2.50 $m^3.h^{-1}.m^{-2}$ at 50 Pa	0.053 $dm^3.s^{-1}.m^{-2}$
	Class 3 (Min)	2.50 $m^3.h^{-1}.m^{-1}$ at 50 Pa	0.053 $dm^3.s^{-1}.m^{-1}$
France NF P20 302	A1	20-60 $m^3.h^{-1}.m^{-2}$ at 100 Pa	0.266-0.798 $dm^3.s^{-1}.m^{-2}$
	A2	7-20 $m^3.h^{-1}.m^{-2}$ at 100 Pa	0.093-0.266 $dm^3.s^{-1}.m^{-2}$
	A3	<7 $m^3.h^{-1}.m^{-2}$ at 100 Pa	<0.093 $dm^3.s^{-1}.m^{-2}$
Germany DIN 18055	A Building Height 0-8 m Above Grade	6.00 $m^3.h^{-1}.m^{-1}$ at 50 Pa	0.126 $dm^3.s^{-1}.m^{-1}$
	B-D Building Height > 8 m Above Grade	3.00 $m^3.h^{-1}.m^{-1}$ at 50 Pa	0.063 $dm^3.s^{-1}.m^{-1}$
Italy UNI 7979	A1	8.00 $m^3.h^{-1}m^{-1}$ at 50 Pa 31.00 $m^3.h^{-1}m^{-2}$ at 50 Pa	0.168 $dm^3.s^{-1}.m^{-1}$ 0.651 $dm^3.s^{-1}.m^{-2}$
	A2	4.00 $m^3.h^{-1}.m^{-1}$ at 50 Pa 13.00 $m^3.h^{-1}.m^{-2}$ at 50 Pa	0.084 $dm^3.s^{-1}.m^{-1}$ 0.273 $dm^3.s^{-1}.m^{-2}$
	A3	1.40 $m^3.h^{-1}.m^{-1}$ at 50 Pa 4.80 $m^3.h^{-1}.m^{-2}$ at 50 Pa	0.029 $dm^3.s^{-1}.m^{-1}$ 0.101 $dm^3.s^{-1}.m^{-2}$

Country/Standard Ref.	Description	Quoted Leakage Value	Leakage at 1 Pa (Flow Exponent assumed 0.66)
Netherlands NEN 3661	Building Height up to 15 m (Normal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 75 Pa	0.145 $dm^3.s^{-1}.m^{-1}$
	Building Height 15-40 m (Normal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 150 Pa	0.092 $dm^3.s^{-1}.m^{-1}$
	Building Height 40-100 m (Normal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 300 Pa	0.058 $dm^3.s^{-1}.m^{-1}$
	Building Height up to 15 m (Coastal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 300 Pa	0.058 $dm^3.s^{-1}.m^{-1}$
	Building Height 15-40 m (Coastal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 300 Pa	0.058 $dm^3.s^{-1}.m^{-1}$
	Building Height 40-100 m (Coastal Exposure)	2.50 $dm^3.s^{-1}.m^{-1}$ at 450 Pa	0.044 $dm^3.s^{-1}.m^{-1}$
New Zealand NZS N4211:1987	Airtight	0.60 $dm^3.s^{-1}.m^{-1}$ at 150 Pa 2.00 $dm^3.s^{-1}.m^{-2}$ at 150 Pa	0.022 $dm^3.s^{-1}.m^{-1}$ 0.073 $dm^3.s^{-1}.m^{-2}$
	Moderate Air Leakage	2.00 $dm^3.s^{-1}.m^{-1}$ at 150 Pa 8.00 $dm^3.s^{-1}.m^{-2}$ at 150 Pa	0.073 $dm^3.s^{-1}.m^{-1}$ 0.293 $dm^3.s^{-1}.m^{-2}$
	Low Air Leakage	4.00 $dm^3.s^{-1}.m^{-1}$ at 150 Pa 17.00 $dm^3.s^{-1}.m^{-2}$ at 150 Pa	0.147 $dm^3.s^{-1}.m^{-1}$ 0.623 $dm^3.s^{-1}.m^{-2}$
Sweden	All Buildings	1.70 $m^3.h^{-1}.m^{-2}$ at 50 Pa 5.60 $m^3.h^{-1}.m^{-2}$ at 300 Pa	0.036 $dm^3.s^{-1}.m^{-2}$ 0.036 $dm^3.s^{-1}.m^{-2}$
	Buildings >8 Storeys	7.90 $m^3.h^{-1}.m^{-2}$ at 500 Pa	0.036 $dm^3.s^{-1}.m^{-2}$
Switzerland SIA 331	Building Height 0-8 m	5.65 $m^3.h^{-1}.m^{-1}$ at 150 Pa	0.056 $dm^3.s^{-1}.m^{-1}$
	Building Height 8-20 m	8.95 $m^3.h^{-1}.m^{-1}$ at 300 Pa	0.056 $dm^3.s^{-1}.m^{-1}$
	Building Height 20-100 m	14.25 $m^3.h^{-1}.m^{-1}$ at 600 Pa	0.056 $dm^3.s^{-1}.m^{-1}$
United Kingdom BS6375:Part 1:1989	Openable - Design Wind Pressure (Exposure) <1600 Pa	6.34 $m^3.h^{-1}.m^{-1}$ at 50 Pa	0.133 $dm^3.s^{-1}.m^{-1}$
	Openable - Design Wind Pressure (Exposure) >=1600 Pa	4.84 $m^3.h^{-1}.m^{-1}$ at 50 Pa	0.102 $dm^3.s^{-1}.m^{-1}$
	Fixed - Design Wind Pressure (Exposure) <1600 Pa	1.00 $m^3.h^{-1}.m^{-1}$ at 200 Pa	0.008 $dm^3.s^{-1}.m^{-1}$
	Fixed - Design Wind Pressure (Exposure) >=1600 Pa	1.00 $m^3.h^{-1}.m^{-1}$ at 300 Pa	0.006 $dm^3.s^{-1}.m^{-1}$
	Fixed - High Performance	1.00 $m^3.h^{-1}.m^{-1}$ at 600 Pa	0.004 $dm^3.s^{-1}.m^{-1}$
	Openable - High Performance	6.60 $m^3.h^{-1}.m^{-1}$ at 600 Pa	0.02 $dm^3.s^{-1}.m^{-1}$
USA ASHRAE 90-80	All	0.77 $dm^3.s^{-1}.m^{-1}$ at 75 Pa	0.045 $dm^3.s^{-1}.m^{-1}$

Standards, Recommendations and Legal Codes of Practice - Doors

Country/Standard Ref.	Description	Quoted Leakage Value	Leakage at 1 Pa (Flow Exponent assumed 0.66)
Canada CGSB 82-GP-2M	Sliding Glass With Aluminium Frame	2.50 $dm^3.s^{-1}.m^{-2}$ at 75 Pa	0.145 $dm^3.s^{-1}.m^{-2}$
Denmark DS-418	Assumed Value (When True Value Not Known)	0.50 $dm^3.s^{-1}.m^{-1}$ at 50 Pa	0.038 $dm^3.s^{-1}.m^{-1}$
USA ASHRAE 90-80	Residential (Sliding Glass)	2.50 $dm^3.s^{-1}.m^{-2}$ at 75 Pa	0.145 $dm^3.s^{-1}.m^{-2}$
	Residential (Entrance-Swinging Doors)	6.35 $dm^3.s^{-1}.m^{-2}$ at 75 Pa	0.367 $dm^3.s^{-1}.m^{-2}$
	Non-Residential	17.00 $dm^3.s^{-1}.m^{-2}$ at 75 Pa	0.984 $dm^3.s^{-1}.m^{-2}$

Standards, Recommendations and Legal Codes of Practice - Walls, Ceilings and Floors

Country/Standard Ref.	Description	Quoted Leakage Value	Leakage at 1 Pa (Flow Exponent assumed 0.66)
Netherlands Building Decree. Issued December 16, 1991	Flooring	$20x10^{-6}$ $m^3.s^{-1}.m^{-2}$ at 1 Pa	0.020 $dm^3.s^{-1}.m^{-2}$

{Source: "An analysis and data summary of the AIVC's numerical database", Orme et al, 1994, Air Infiltration and Ventilation Centre}

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The Air Infiltration and Ventilation Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

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