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HOME INDOOR ENVIRONMENT

Houses are spaces for human habitation, created as a viable alternative to living outdoor. The created indoor environment is meant to ensure health and safety of the occupants, and to keep them comfortable.

The home indoor environment intensively interacts with humans (e.g. lighting, acoustics, thermal comfort, indoor air quality, spread of diseases, sleeping quality, safety, etc.). An important factor is the effect of the home indoor environment to the air to which the inhabitants are exposed. It is a complex system that is a result of the interaction between the building, the construction techniques used, contaminant sources, the building occupants and the outdoor sources. It is affected by the original design and subsequent modifications in the structure and systems, building materials and furnishings, processes and activities.

Poor indoor air quality, noise, excess humidity and mould growth, thermal discomfort, substances such as formaldehyde, asbestos, lead and radon, lack of hygiene and sanitation equipment and crowding are some of the possible health threats to be found in dwellings. In the last decade several interdisciplinary reviews of the scientific literature conducted in Sweden (Ahlbom et al., 1998; Sundell, 1999), in the Nordic countries (Andersson et al., 1997; Bornehag et al., 2001) and more generally in Europe (Wargocki et al., 2002; Schneider et al., 2003; Bornehag et al., 2004) have shown a strong evidence of an association between indoor environmental exposures and human health (e.g. risk factors such as dampness, ventilation, pets, and house-dust mites, and health effects such as allergy and asthma, airway infections and Sick Building Syndrome).

BUILD TIGHT, VENTILATE RIGHT

Since the energy crisis in the mid 1970s, energy saving has become a priority in most industrialized countries for economic and ecological reasons. More recently, environmental concerns of a global climate change have reinforced the urgency of rational energy use. The drive for energy saving may appear to conflict with good indoor air quality. In fact, reducing ventilation to reduce energy consumption leads to higher levels of indoor pollutants and humidity, thus increasing the exposure of the occupants. Excess air moisture may result in dampness problems. Dampness indoors can result in chemical and microbial processes that can release toxic substances as well as induce the proliferation of house-dust mites. In combination with the implementation of new synthetic materials for fittings and furnishings as well as the use of new consumer products, human indoor exposure has been changed substantially. Negative health consequences of energy saving measures (e.g. insufficient ventilation) are often indicated. A classical example showing the indirect connection between the changes in people's health status and energy saving measures, is a study from Germany (von Mutius et al., 1998a) where in 1998 the prevalence of atopic sensitization (1990:19.3% vs. 1998: 26.7%) and Allergic rhinitis, also named hay fever, (2.3% vs. 5.1%) among children in former East Germany increased significantly and more rapidly than in West Germany (von Mutius et al., 1994) after the German reunification (1990). The children had spent their first three years of life under socialist living conditions and were later exposed to a western style of life. Von Mutius (1998b) suggested several explanations for this change among those including substantially changed indoor conditions (gas heating, wall-to-wall carpets) and significantly more dampness problems. The risk from sources of indoor chemical emissions as well as mould growth is expected to increase at lower ventilation rates, because indoor concentrations and humidity would increase respectively.

Reduced ventilation rates means normally increased concentrations of building-related pollutants, including moisture. Seppanen and Fisk (2004) pointed out that the existing literature indicates that ventilation has a significant impact on several important human outcomes including: (1) communicable respiratory illnesses; (2) sick building syndrome symptoms; (3) school performance and productivity, and (4) perceived air quality (PAQ) among occupants or sensory panels (5) respiratory allergies and asthma. However, only few studies on the association between health effects and ventilation rates in homes have been reported (e.g. Oie et al., 1999; Bornehag et al., 2005). Oie et al. (1999) found that the risk of bronchial obstruction was not directly associated with the ventilation rate in homes. However, the Odds Ratios (OR) of bronchial obstruction were higher in the low air change group (ACH $\leq 0.5\ h^{-1}$) than in the high air change group (ACH $>0.5\ h^{-1}$) owing to exposure to environmental tobacco smoke (low ACH: OR 1.8; high ACH: OR 1.5), dampness problems (low ACH: OR 9.6; high ACH: OR 2.3), and the presence of textile wall paper (low ACH: OR 3.7; high ACH: OR 1.7) and plasticizer-containing surfaces (low ACH: OR 12.6; high ACH: OR 2.6). These results show that having an air change rate lower than $0.5h^{-1}$ increases the risk of bronchial obstruction because the concentration of pollutants due to environmental tobacco smoke, moulds, textile wall papers and plasticizer-contaminant surface increase. In a study by Bornehag et al. (2005), 198 sick children (a child is considered sick when he has at least two of three symptoms: wheezing, rhinitis, eczema) and 202 healthy children, living in 390 homes, were examined by physicians and ventilation rates were measured by a passive tracer gas method. The sick children were living in single-family homes with significantly lower ventilation rates than healthy children. A dose-response relationship was further indicated, meaning that children living in homes with ventilation rate of $0.17\ h^{-1}$ have higher risk to have at least two of three symptoms: wheezing, rhinitis, eczema compared to those in homes with $0.29\ h^{-1}$, as well as those with $0.29\ h^{-1}$ compared to those with $0.38\ h^{-1}$ and so on (Figure 1). The authors concluded that a low-ventilation rate in homes may be a risk factor for allergies among children and they suggested that families with allergic children should be given the advice to have good ventilation in their homes.

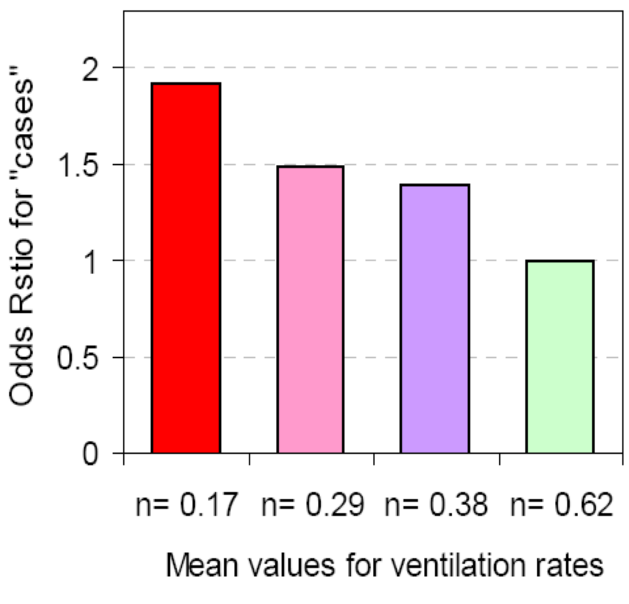

Figure 1 Association between ventilation rate (ach) indoor and case status in single-family houses (Bornehag et al 2005)

Kovesi et al. (2007) measured CO_2, that is an indicator for the ventilation rate, in 49 homes in Canada. Reported respiratory infection was significantly associated with mean CO_2 levels (OR 2.85 per 500-ppm increase in mean indoor CO_2).

Even limited as a number, results of such studies are consistent with the idea that low ventilation rates strengthen the effects of indoor air pollutants.

Scientific literature on the effects of ventilation on health, comfort, and productivity in non-industrial indoor environments (offices, schools, homes, etc.) has been reviewed by a multidisciplinary group of European scientists, called EUROVEN (Wargocki et al. 2002), with expertise in medicine, epidemiology, toxicology, and engineering. According their conclusions the literature indicates that air change rates above 0.5 h^{-1} in homes reduce the degree of infestation of House Dust Mites (HDM) in Nordic countries. Taking into account the causal link between house dust mites infestation and asthma and allergies, these data suggest that decreased ventilation may exacerbate allergies. The literature on HDM (e.g. Harving et al., 1994; Sundell et al., 1995; Crowther et al., 2002) indicates that inadequate ventilation in homes constitutes a major risk factor for health effects. A literature review by Ridley et al. (2006) identified possible connective routes between ventilation and respiratory problems. They concluded that there is a general consensus that a link exists between ventilation rates in dwellings and respiratory hazards (e.g. HDM) as well as that links exist between these respiratory hazards and respiratory problems.

It is well established that ventilation rates in homes in northern Europe have been reduced during recent decades as a result of energy conservation measures. About 60% of the multi-family houses and about 80% of the single-family houses in Sweden (Bornehag et al., 2005) and 36% of all residences in Oslo, Norway (Oie et al., 1998) had less than 0.5 air change rates per hour. Furthermore, the building design in eastern European countries is now rapidly changing and the leaky structure buildings are also becoming tight. There is no evidence that the situation in Italy is different. There are no available data showing that Italian homes are leakier or tighter and an extensive study would be needed to assess the average air change rate in Italian residential buildings. Nevertheless the value of 0.3 air change rate per hour introduced in the recent standard UNI TS 11300 (2008) for energy certification (justified as representative of a supposed present condition) is in some way misleading as the Energy Performance of Building Directive 2002/91/EC (EPBD) explicitly states (articles. 2 and 4) that the energy conservation goals should be achieved without negative effects on health (EPBD 2002).

To satisfy the energy and health needs, uncontrolled ventilation should be avoided. The house should be tight and outdoor air by means of mechanical or natural ventilation should be provided. Letting the occupant opening and closing the windows is not a good solution of the problem because people rapidly get adapted to high level of pollution as also shown in a recent Italian study (D'Ambrosio and Ianiello, 2008), but on the other hand, if a mechanical ventilation system is installed the occupants should have always the possibility to open the windows.

WHY IT IS THOUGHT THAT 0.5 ACH IS ENOUGH

It is a common practice to think that 0.5 ACH is the right ventilation rate in homes. In this paragraph it is explained from which considerations the 0.5 value came from and why it is not a sufficient index for describing the needed ventilation. The aims of ventilation in homes are to dilute pollutant indoors and to avoid the growing of mould.

The 0.5 value came out from an attempt to cope with these two problems and for historical reasons.

<u>Dilute bioeffluents</u>

Oxygen is necessary for metabolism of food to sustain life. Carbon and hydrogen in foods are oxidized to CO_2 and H_2O, which are eliminated by the body as waste products. Foods can be classified as carbohydrates, fats, and proteins, and the ratio of carbon to hydrogen in each is somewhat different. The respiratory quotient (RQ) is the volumetric ratio of carbon dioxide produced to oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.8 for a diet of 100% protein and 1.00 for a diet of 100% carbohydrates. A value of RQ = 0.83 applies to a normal diet mix of fat, carbohydrate, and protein. The rate at which oxygen is consumed and carbon dioxide is generated depends on physical activity. A simple mass balance equation gives the outdoor air flow rate needed to maintain the steady-state CO_2 concentration below a given limit.

$$V_o = N/(C_s - C_o)$$

where
V_o = outdoor air flow rate per person [l/s*person]
N = CO_2 generation rate per person [l/s]
C_s = CO_2 concentration in the space [l/l, ppm]
C_o = CO_2concentration in outdoor air [l/l, ppm]

For example, at an activity level of 1.2 met units, corresponding to sedentary persons, the CO_2 generation rate is 0.31 l/min (≈18.6 l/h, 0.005 l/s).
Laboratory and field studies have shown that with sedentary persons about 7.5 l/s (27 m^3/h) per person of outdoor air will dilute odors from human bioeffluents to levels that will satisfy a substantial majority (about 80%) of unadapted persons (visitors) to a space. Thus 7.5 l/s per person is a value proposed for effective dilution odors from human bioeffluents and not from health point of view.
If the ventilation rate have to be held to 7.5 l/s (27 m^3/h) per person, the resulting steady-state CO_2 concentration relative to that in the outdoor air is,
Cs - Co = N/Vo = 0.005/7.5 = 0.000689 l/l or ≈700 ppm
CO_2 concentrations in acceptable outdoor air typically range from 300 to 500 ppm. Higher CO_2 concentrations in the outdoor air can be an indicator of combustion and/or other contaminant sources.

In case of occupancy 1 person per 20 m^2 and room height of 2.5 m, 27 m^3/h of air corresponds to air change rate of 0.54 h^{-1}. For the typical Italian condition four persons live in a 100 m^2 house. The ceiling height is 2.7 m. providing each person with 27 m^3/h of air corresponds to air change rate of 0.4 h^{-1}. From what previously written comes the first important aspect, not air change rate itself rather than the amount of supplied fresh air and occupancy rate is more relevant and is of importance in satisfying the personal needs. The needed airflow rate should be calculated each time as a function of the available space and the number of occupants and the occupancy frequency.

The 0.5 ACH value was calculated to get acceptable air quality when the main pollution source was humans (bioeffluents). Since decades it has been recognized that humans are not the only pollution source in buildings. For this reason, in all the recent standards for the calculation of the airflow rate in the non-residential buildings, e.g. ASHRAE 62.1 (2004), and EN 15251 (2007) explicitly acknowledge the existence of non-occupant contaminant sources by also including a ventilation requirement per unit floor area. Thus, in determining the ventilation requirement of a space, the per-person requirement is multiplied by the number of people and added to the floor area multiplied by the building requirement. This update has not been done for airflow for homes! Therefore, more than 0.5 ACH should be provided to residential buildings.

Humidity and dampness

The other main purpose for ventilation in building is to control the level of indoor humidity. Based on personal activities, the individual contribution to humidity indoors is approx. 2.5 kg water per day. Investigations in Scandinavia (Aggerholm and Reinhold, 1989) revealed that contribution to about 3.5 g water per kg of air will not result in damp problems, thus a value of 7 l/s per person was

calculated as efficient to remove the excess humidity. When taking in account the same occupancy rate as above, an air change rate of 0.5 h^{-1} comes out.
And here comes the second point, again not the air change rate itself rather than the personal contribution to the humidity level indoors and the occupancy level as well as the volume of the room/residence is of importance. And again the calculations are based on a steady-state base. If only the water produced by a person at rest (approx. 30 g water/h) is taken into account in calculations, a value of approx. 3 l/s per person can be calculated. An excess amount of water can be produced in processes as cooking (approx. 600-1500 g/h), gas burning (approx.1500 g per 1m^3 gas), taking shower (approx. 2600 g/h), drying of clothes (approx. 100-500 g/h), etc. In such cases, higher supply of fresh air than 7 l/s per person is even needed. The CEN document CR 14788 gives further details on moisture production in dwellings.

A calculation for a specific situation can be performed, based on the steady-state balance equation

$$V_o = G/\rho*(x_i - x_o)$$

where
V_o = outdoor air flow rate per person [m^3 /h]
G = humidity generation rate per person [g/h per person]
x_s = absolute humidity in the space [g/kg]
x_o = absolute humidity in outdoor air [g/kg]
ρ= air density [kg/m^3]

Historical reasons
The knowledge about the CO_2 value of 1000 ppm (700 ppm above the outdoor level), which transformed in ventilation rates, corresponds to 0.5 ACH is more than 130 years old. Recently, in "On the history of indoor air quality and health" Sundell (2004) gave a short overview on the topic. To major extend the "1000 ppm" value is based on the observations and work of Max Joseph von Pettenkofer (1818–1901). Pettenkofer stated that air was not fit for breathing if the CO_2 concentration (with man as the source) was above 1000 ppm, and that good indoor air in rooms where persons stay for a long time should not exceed 700 ppm in order to keep the persons comfortable. The 1000 ppm value (including CO_2 from ambient air) is as a limit value for an adequately ventilated room (700 ppm in bedrooms), including a certain margin for the use of oil burners for lighting.

CONCLUSIONS
In the paper it has been shown from where the 0.5 ACH value came from. It has been demonstrated that not the air change rate but the airflow rate per person, the occupancy and the pollution generation are the key parameters to determine the required ventilation rate. Thus, the use of the amount of the fresh air supplied per person and for the pollution source rather than air change rate is recommended.

It has also been reported that where the air flow rate has been measured the actual air change rate was much lower than the minimum requirement of 0.5. There are no available data for Italy.

Particular attention should be paid, when promulgating new laws and regulations, in establishing proper values for ventilation rates, as energy efficiency in buildings must be achieved without sacrifice of comfort, degradation of the building and, first of all, damage to health.

But the most important point is that, even though, a limited number of studies on ventilation and health is available, there is strong evidence on the direct impact of ventilation on our wellbeing, and several authors affirmed that more than 0.5 ACH should be supplied in dwellings.

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DEFINIZIONI

Sintomi della sindrome da edificio malato (SBS)
I sintomi della sindrome da edificio malato (*Sick Building Syndrome, SBS*) sono l'insieme di sintomi non specifici, sperimentati dagli occupanti dell'edificio e collegati alle caratteristiche dell'edificio e dell'ambiente interno. Tra questi: irritazione agli occhi, al naso e alla pelle, mal di testa, senso di fatica, e di difficoltà a respirare. I sintomi spariscono quando la persona si allontana dall'edificio e non sono collegati a nessuna malattia specifica.

Qualità dell'aria percepita (PAQ)
La qualità dell'aria percepita (Perceived Air Quality, PAQ) è la qualità dell'aria interna dal punto di vista della percezione umana. Il decipol è l'unità di misura della qualità dell'aria percepita: un decipol (dp) è la qualità dell'aria percepita (PAQ) in un ambiente con un carico sensoriale di un olf (una persona standard) ventilato da 10 l/s. Il decipol è stato sviluppato per quantificare l'influenza di una sorgente interna di inquinanti sulla percezione umana della qualità dell'aria. L'olf è l'unità di misura dell'intensità di una sorgente d'inquinanti: un olf è l'intensità sensoriale di inquinanti generati da una persona adulta standard. Questa è definita come un adulto medio che lavora in un ufficio o in un posto simile, seduto e che si trova in comfort termico, che ha uno standard di igiene equivalente a 0,7 docce/giorno. L'olf è stato definito per quantificare l'intensità di una sorgente di inquinanti dal punto di vista della percezione umana.

What is an odds ratio?
The odds ratio is a way of comparing whether the probability of a certain event is the same for two groups. An odds ratio of 1 implies that the event is equally likely in both groups. An odds ratio greater than one implies that the event is more likely in the first group. An odds ratio less than one implies that the event is less likely in the first group. In medical and social science research the odds ratio is commonly used as a means of expressing the results in some forms of clinical trials, in survey research, and in epidemiology, such as in case-control studies.

Sensibilizzazione atopica
Sensibilizzazione atopica è una sensibilizzazione di una parte del corpo che non è in diretto contatto con l'allergene

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