# WS 30 INTELLIGENT BUILDINGS AND INDOOR AIR QUALITY

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## WHY IS AIR QUALITY IMPORTANT?

The most persistent memory of any space is often its odour. Every building has its individual scent. The sense of smell is acutely sensitive. Strong emotional and past experiences are awakened by the olfactory sense. Odours can also influence cognitive processes which affect creative task performance as well as personal memories besides, odours can also affect moods (Clements-Croome, 2000). The olfactory epithelium is situated in the roof of the nasal cavity and contains thousands of cells which detect odours. Many different types of sensors line the cells' surfaces. Odour molecules from the air land on them and they produce nerve impulses which are transmitted along the olfactory nerve to the brain. The olfactory epithelium looks like a mass of hairs (cilia) and strands. The cilia bear tiny studs which are thought to be the points of interaction between the air and the nerve receptor cell. Human beings have about six million sensory cells in the olfactory system. Chemical particles in the air we breathe first encounter these sensory cells before the air passes through the olfactory epithelium which produces the mucus that helps to trap and hold airborne chemicals. This is the last filter before gaseous exchange occurs via the alveoli across the lungs to the blood stream. The nose is often referred to as the *air conditioner of the body* and indeed it has many varying degrees of sensitivity. There also appears to be a second tier olfactory system where, according to the work of Berliner (1996), there are receptors in what is called Jacobson's organ (the physiological term for this is *vomeronasal organ*) which deal with steroidal vomeropherins from human skin and sends messages about them to the limbic areas of the brain (Watson, 1999).

Lavoisier in about 1777 carried out studies on the effect of oxygen and carbon dioxide in the air of crowded rooms and he concluded that excess $C0_2$ rather than a reduction of oxygen causes sensations of stuffiness and bad air. Pettenkofer (1862) concluded that neither oxygen nor carbon dioxide were responsible for bad air but rather it was the biological contaminants. Nevertheless, Tregold (1824), Billings (1884) and others attempted to calculate the amount of fresh air required to prevent the spread of disease and let people breathe fresh air. There is a wide range of estimates ranging from 2 to 28 l/s per person. ASHRAE Standard 62-1989 accepts 7.5 l/s which is the lowest permissible ventilation rate. Many factors are involved in the definition of air quality. Particulate and gaseous contents of the atmosphere are clearly important but the temperature, humidity and velocity of the air passing over the human body are also important. A neglected area of work is concerned with *freshness.*

## FRESHNESS (CLEMENTS-CROOME 1996)

The word *fresh* has quite a large span of meaning which can be associated with words like new, cold, cleanliness, salubrious, preserved, and ventilated. It is the *salubrious* and *ventilated* qualities which are being sought in environmental design. Other words such as *airy* can mean well ventilated or draughty but they usually have a narrower range of meaning. The antonyms could be *stale* (no longer fresh, musty) or *stuffy* (muggy, close, badly ventilated, musty). In general, warm to hot and airless environments are stuffy, whereas warm to cool ones are airy or fresh.

The impression and sensation of freshness, however, is stimulated along two sensory pathways. Air can have a cooling effect as it passes over the skin. The free or encapsulated nerve endings unevenly spread over the skin are very sensitive to temperature changes; variations of less than 0.01°$Ks^{-1}$ can be perceived according to Geldard (1972) who concludes however, that skin temperature is not a trustworthy predictor of thermal sensations. The strength of the stimulus can be interpreted as the pressure of an airstream on the skin which can be expressed as the rate of change of momentum. This stimulus can cause a heat exchange if there is a temperature difference between the air and the skin, a kinetic pressure on the skin, and a mass transfer if the vapour pressure of the airstream is different from that at the surface of the skin. All these effects contribute towards the impression of freshness, the level of which depends on the sensitivity of the nerve receptors and their body location. The sensible cooling effect of the air depends on the surface roughness, shape and velocity magnitude. The latent cooling is proportional to the vapour pressure difference between the air and the skin; this becomes very important at about 28°C. The air velocity fluctuations in terms of frequency and turbulence intensity are also important because they cause changing stimulus and adaptation levels.

The other sensory pathway is via the nose. This is a comparatively neglected area of research and yet the air we breathe passes very quickly via the olfactory systems to the respiratory where oxygen from the air is transferred at the lung walls to the blood and hence circulated around the body. The link from the external environment to the blood and the brain is almost immediate. Air contains several gases besides oxygen and nitrogen and in addition may have smoke particles, dust, formaldehyde, radon or other bioeffluents.

The intensity of odours is measured in olfactie units; low levels are 10 to 14 olfacties for rubber rising to 400 olfacties for very odorous substances. Fanger (1998) defines units for subjective evaluations of air quality in terms of the *olf* and the *decipol.* One olf represents the source strength or power of the air pollution relative to a standard person. The olf is comparable to lumens of light, or watts of noise. The perceived level of air pollution is quantified in decipols, analogous to lux or decibels, where one decipol is the pollution caused by one person ventilated by 10 1 $s^{-1}$of unpolluted air. (1 olf = 10 dpol). Fanger suggests that outdoor air has a decipol range of 0.01 to 0.1; healthy buildings are rated at under 1 dpol and sick buildings at 10 dpol. Pollution strengths vary depending on the activity, whether people are smoking, the materials in the space and the cleanliness of the airflow system. For example a range of 1-11 olf covers people with activity levels of 1 to 6 met; smokers average 6 olf but can be as high as 25 olf; materials may vary from 0 to 0.5 olf per $m^2$ floor area.

There exists very little data on the optimum ranges of air conditions which are best for the nasal and respiratory airways. From personal experience we know dry air leads to stuffy noses and blocked sinuses; it also impedes the mucous flow over the respiratory membranes impeding the cilia motion and decreasing their cleaning efficiency. Beyond this our knowledge is meagre.

Bedford (1974) discussed the freshness factor and concluded that:

- people desire more air velocity changes in summer than in winter partly because the air temperature is higher during hot weather and also because the relative humidity is higher.

- there is a significant correlation between freshness and variability of air velocity in summer.

- humidities above 55% are more likely to induce lethargy.

- in a set of experiments impressions of freshness were judged to be dependent on air velocity and air temperature at head level; the results showed that the values of air velocity of between 0.15 and 0.25 $ms^{-1}$ selected for design purposes were too low for comfort.

- air movement is welcome in humid environments.

- warm wall environments may be both fresher and more pleasant than warm air ones, a factor not affirmed in experiments carried out by McIntyre (1980). It is probably true, however, that warm air systems are more likely to cause stuffy noses; this is less likely to occur with radiant ones because the air temperature is lower.

The value of freshness as the time variant aspect of thermal comfort providing contrast and change has been discussed by Croome (1981) and Purcell (1987) based on arousal level theory. These field experiments aim to see how freshness can be evaluated from the parameters commonly used by designers.

## ENVIRONMENT, ENERGY AND WELL-BEING

The largest impact of buildings on the outdoor environment during the whole life cycle is due to the energy used to ensure a comfortable and healthy indoor climate.
According to Orme (1998) ventilation accounts for between 25 - 30% of the total building energy use. There are large disparities in the energy consumption of similar buildings in similar locations and this is due to various levels of thermal insulation, services system efficiencies, differences in building construction, more or less effective use of passive design techniques, occupancy behaviour and building management. Behaviour of occupants reflect their expectancies and life style which are demonstrated in their workplace as well as their homes. Facilities management is now recognised as an art which not only looks after systems which make the building operate but also the people. Roulet (1995) shows the *total energy index* (annual energy use divided by the gross heated floor area) for 56 European office buildings. In this sample the largest energy consumption was more than six times the smallest. This variation can be reduced in the case of highly insulated buildings but overall it is occupancy behaviour which contributes the largest effect in this variation.

Roulet (1998) shows how the *energy index* varies in relation to the *building symptom index*, (average number of symptoms per occupant experienced during the past month selected from a list of twelve) in 56 European office buildings. In general the energy consumption is more in less healthy buildings. In this particular case study the correlation co-efficient was 0.43 with a 95% probability ($p = 0.05$ to $0.07$).

The variation in energy consumption of building arises at the design, construction, commissioning and facilities management stages. Many buildings give the occupant very poor control of their environment and this is not only inconvenient but is psychologically unacceptable because the occupants do not feel that they have a role in controlling their surroundings.

The basic intention of buildings is that they should be planned, designed, built and managed to offer an environment in which occupants can carry out their work and feel well and to some extent be refreshed by the environment. Unhealthy buildings result in a loss of productivity and every working hour lost costs as much as a kWh hence the occupants well-being in monetary terms is even more important than energy use, Roulet (1998). Salaries usually amount to about 90% of the total cost of an organisation and so very small changes in productivity will be economically viable. Many case studies are described in Clements-Croome (2000), in which it becomes clear that it is beneficial to spend more on designing good indoor air quality systems as this considerably improves the occupants well-being and results in a payback period in a typical office building of under two years. Geens (1998) carried out a small scale study of Public Houses and found that better ventilation systems increased the profits from increased food and drink sales, which gave an average payback of under three months.

## VENTILATION RATES

Seppänen et al (1999) has made a comprehensive review of over twenty studies with over thirty thousand subjects and found that ventilation rates below 10 $ls^{-1}$ per person result in lower air quality and worsening health problems. Risk of sick building syndrome is reduced and perceived air quality is improved when the ventilation rates increase from 10 to about 20 $ls^{-1}$ per person. The work also indicated that carbon dioxide concentrations below 800 ppm are preferable. An indoor carbon dioxide concentration of 800 ppm responds to a fresh air ventilation rate of 11.6 $ls^{-1}$ pp with sedentary activity according to ASTM D 6245-98 (1998). This assumes that the concentration of carbon dioxide in the outdoor air is about 350 ppm. The results of Jaakkola (1995) indicate that each $1s^{-1}$ per person change in ventilation rate over the range 0 to 25 $ls^{-1}$ per person is associated with a relative risk of 1.1 for experiencing symptoms. Thus a 5 $ls^{-1}$ per person decrease of ventilation rate would increase the proportion of occupants with frequent upper respiratory symptoms from 25 to 40% with a similar increase for eye symptoms.

Ventilation rates for acceptable indoor air quality are currently assessed by using ASHRAE 62 Standard (1989). In this there are two standard procedures for estimating the amount of fresh air required. The first of these is referred to as the *ventilation rate* and is a *prescriptive approach* stating that for an office building there is a requirement of 10 l/s of fresh air per person (non-smoking). A comparison of standards for indoor environment is given in F9.2 of ASHRAE Handbook 1997 on Fundamentals.

The second procedure is based on a *performance approach* using public knowledge about indoor air quality. This approach has originated in Europe (EEC,1992; CEN, 1994). In these proposals the ventilation requirements are computed for health and comfort purposes and the higher of the resulting values is recommended to be applied to the particular building being designed. This system is bases on the olfactory process using the *olf* and *decipol* (Fanger 1988). This approach recognises that pollutions in the atmosphere are sensed by the olfactory system and there are objective and subjective reactions to the pollutants.

## PROBLEMS OF VENTILATION DESIGN

Like all environmental problems there are a number of confounding factors which influence the choice of ventilation rate. Personal characteristics, work related factors, building related factors as well as indoor environmental factors all need to be appreciated in dealing with environmental design problems. Table 1 (Seppänen 1999) describes some of the potential confounding factors which can trigger particular reactions in the environment which can lead to sick building sickness syndrome.

**Table 1 Examples of potential confounding factors in studies of ventilation rates and SBS symptoms.**

| Personal Characteristics | Work-Related Factors | Building-Related Factors | Indoor Environmental Factors |
|---|---|---|---|
| Gender | Job stress or satisfaction | Type of ventilation system | Air temperature |
| Atopy (allergic disposition) | Use of carbonless copy paper | Type of humidification | Air humidity |
| History of asthma<br><br>Smoking history | Use of or proximity to photocopy machines | Quantity of carpet or textile surfaces | Environmental tobacco smoke |
| Job type | Use of video display terminals | Sealed windows<br>Building age | Dusty surfaces |
| Medical treatment (especially for asthma and atopy) | | | |

## INDOOR AIR QUALITY AND INTELLIGENT BUILDINGS

Woods (1998) gives a rational model that relates human response, exposures, systems, sources (or loads) and economics. In this model the sources of the loads may be thermal, contaminants, lighting or sound and in effect constitute the first costs. These loads are imposed on the systems which comprise the building structure, envelope, services or enclosures and incur operating costs. People within the building are exposed to these effects and sense these factors and respond to them which results in energy patterns of use. At a more subtle level the human responses affect the health and well-being of people which is a large contributory factor towards productivity.

Woods (1998) proposes a control strategy by developing a concept of *building energy efficiency.* This model focuses on design alternatives requirements to achieve acceptable exposures but at the same time minimises energy wastes. This model recognises that energy *effectiveness* relies on using the energy where and when it is needed, whereas the term energy *efficiency* only crudely refers to outputs and inputs without any concern as to the distribution. Woods (1998) reckons that solar buildings with a reasonable control strategy achieve an annual energy requirement of 50% less compared with conventional buildings. Again this work emphasises the interdependent nature of health, energy and management.

## ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

Woods (1998) proposes the idea of *continuous accountability.* In order to implement this he proposes a system of building diagnostics. A useful analogy is made between medical diagnostics in which the central steps are to develop a knowledge of what is to be measured; use of appropriate instrumentation to measure; an intelligent interpretation of the results; a capability to predict likely performance over time. Building diagnostics can be used throughout the life of a building, beginning with the planning and design stage and through adaptive reuse or demolition. This approach has been used by the Department of Labour, Occupation Health and Safety Administration in the USA, Woods (1998). The following five steps are described by Woods (1998):

- *planning and concept design* : building owners, financiers and designers establish basic performance criteria.
- *detailed design:* performance criteria are translated into prescriptive criteria.
- *commissioning:* evaluation of building performance before occupancy by an independent firm or agency.
- *building operation*: building performance evaluated by qualified team of professionals; the building owner is fully accountable for the success of the building at this stage.
- *building use:* buildings and systems are designed for specific uses and conditions so that if these are exceeded, or the systems are tampered with, then system performance will decrease.

A building diagnostics protocol is proposed by Woods (1998) and it is worthwhile considering this for more universal adoption.

## CONCLUSIONS

Indoor air quality is a vital factor for the health of occupants in buildings. The olfactory sense is very important psychologically as well as physiologically. The air we breathe ultimately affects the efficiency of our thinking. Intelligent buildings are ones that enhance human work performance. There is considerable value in demonstrating to clients the value of spending more capital on high quality buildings which promote good airflow characteristics, by using natural, mechanical or air conditioning systems. The process of achieving indoor air quality is a continual one throughout the design, construction, commissioning, facilities management and refurbishment stages of a building’s life. The constituents of the air are many more than we ever realised and there needs to be much more monitoring of these so that we develop a deeper understanding of, and hence ultimately produce healthier workplaces for people at a good economic level. In this way intelligent buildings are produced which are healthy, sustainable, adaptable, economic and responsive to individual as well as corporate needs.

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