Indoor climate and health: What do we really know?

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SUMMARY

Over the last decades, the ability to describe the physical indoor environment and create models of how chemical pollutants, infectious agents and particles are spread, has increased strongly. A huge amount of statistical associations between the indoor environment and health effects has been published, but hardly any specific environmental factor or factors have been conclusively related to specific health effects. This situation has mostly been explained by the complexity of the indoor environment and the diffuse symptoms described. However, our knowledge about the mechanisms behind the registered health effects are sparse and we usually do not fully understand why people react the way they do. Epidemiological methods do have advantages but also have limitations because of the complex low-level exposures, multifactorial environmental factors, and diffuse health outcome measures in indoor environments. In the future, we need to focus more on i) specific well-defined symptoms and ii) mechanistic research (i.e. pathophysiology, identification of cause-effects relationships, and dose-response relationships) and include methods from medicine and neuropsychology.

KEYWORDS

Indoor climate, Health effects, Neuropsychology, Medicine, Holistic view

INTRODUCTION

The title of this paper is quite demanding. We do know a lot about the indoor environment in many buildings and also about the occupants´ perceptions. However, our understanding of the mechanisms (pathophysiology or pathogenesis) behind the effects on humans are limited for single environmental factors in the current low-level range of environmental exposures and our knowledge is also limited about how individual susceptibility and different host factors will influence the outcome. I will discuss some biological mechanisms as a basis for understanding why people react the way they do in some indoor climate problem situations. By necessity, such an approach will be subjective and somewhat speculative in nature but could also, hopefully, serve as a basis for future discussions. Firstly, however, I will give a brief account of the current thinking about indoor climate and health.

Indoor air pollution seriously affects the health of many people, most evident in rural areas in developing countries, where fuels of biomass and coal are used for heating and cooking in crowded and badly ventilated homes (IAIAS, 2006). Furthermore, in the industrialised world, indoor pollutions are important health-related factors, although the health effects discussed are less fatal. Registered increased incidences of allergies, respiratory symptoms and asthma among children has been associated with indoor allergens, moisture or mould-contaminated environments and combustion sources, including environmental tobacco smoke (Bornehag et al., 2004, Nielsen et al., 2007, Lannerö et al., 2008). Emissions from building materials and finishing products, as well as emissions from indoor activities, are also discussed.

During the last ten years an increased interest has been shown as to how viruses and bacteria spread, mainly initiated by the outbreak of SARS and the concerns about the risk of an avian influenza pandemic (Morawska L., 2006; Li et al., 2007). These studies point to the necessary control of the ventilation system and air movements in a building besides efficient hygienic measures. The importance of adequate ventilation has been discussed over the years and has also shown to be closely related to health effects and productivity at work (Seppänen et al., 2006).

A vast amount of scientific papers has been published over the last decades, showing statistical associations between different indoor climate factors (inadequate ventilation, unsuitable temperatures, air humidity, lighting, release of chemical, physical and biological pollutants from structures, construction material and furnishings) and health effects such as allergic and respiratory diseases, discomfort and symptoms often included in the Sick building syndrome (SBS) concept. SBS is not a real medical entity or syndrome but is often used to describe the set of unspecific symptoms reported in many indoor environments with climate problems. The symptoms include general symptoms (fatigue, headache, concentrating difficulties), mucous membrane irritations of the eyes, nose and throat, and dry and irritated skin; it is usually not possible to verify these objectively through medical tests or clinical investigations. Laypersons often relate these symptoms to the indoor environment and describe them mostly as “allergic” symptoms. The results of the epidemiological evaluations usually support some common findings, i.e. people living or staying in moisture and mould contaminated buildings usually report more symptoms, women report complaints and symptoms more often than men do etc. (Bornehag et al., 2004; Gijsbers van Wijk and Kolk, 1997). However, hardly any of the indoor environmental factors can be associated with specific symptoms included in the SBS-symptom umbrella. In order to aim for scientific progress, we should avoid the SBS concept and define each individual symptom in the context of its pathophysiology.

Efforts to develop instruments and measures that would objectively verify physiological changes or perform provocation studies have resulted in the production of instruments and procedures to measure small changes in the nasal mucosa such as acoustic rhinometry, rhinomanometry and rhinostereometry, eye tests such as the break-up time test (BUT), or inflammatory markers such as different cytokines (Hellgren et al., 1997, Hallén and Juto, 1993, Lekander et al., 2004). Experimental studies in climate chambers, or quasi-experimental intervention studies, increase the possibilities for evaluating the exposure effects, controlling for confounding factors (Mølhave et al., 2000; Wieslander et al., 2007). Clinical provocation tests make it possible to classify the cases in medical terms and follow the outcome over time objectively (Rudblad et al., 2005).

The main reason for the difficulties in linking specific pollutants to specific health effects might be that the emissions of chemicals and particles indoors are low, and are mostly several orders of magnitude below occupational threshold limit values (TLV) or health-based indoor guidelines (Nielsen et al., 1998). Based on the difficulties of linking health effects with specific volatile organic compounds (VOCs), the focus has now turned to highly reactive oxidation products and small or ultra-fine particles, sometimes created during the oxidation process with ozone (Weschler et al., 2006; Tamás et al. 2006; Wolkoff et al., 2006). Another obvious reason explaining the difficulties may be the multifactorial indoor environment, including physical, chemical, biological, ergonomic, psychosocial and socioeconomic factors, and the individual vulnerability and anxiety level.

THE BRAIN IN FOCUS

Our brain perceives signals from the outside world but also from the body itself. We have highly specialised, specific senses which have developed during some 100 000 years of evolution. Basic senses, perhaps originally the most important senses for survival, were the senses of smell and taste, although nowadays vision, auditory and somatosensory senses are probably more important. Two typical features of the sense of smell are sensitivity and the rate of adaptation. We now know fairly well how the senses work and which cortical or sub-cortical areas are involved. In fact, millions of signals are handled every second based on a brain structure which is highly specialised and has an extremely developed work distribution between the different brain areas. These areas are distributed in cortex areas in a hierarchical order, being more and more associative, integrated and sophisticated. The most advanced part of the human brain, the frontal lobes, are responsible for cognition and unique "human" characteristics such as empathy and ethics, necessary in an ever more complex social environment. Many of the 10 billion nerve cells (neurons) are included in neural networks responsible for perceptions, learning, memories and actions. Some of these networks are innate; others are changing due to interactions with the environment over the whole lifetime (LeDoux , 2003).

Most of the signals never reach the conscious part of the brain. In fact, only 30 to 40 signals per second can be actively handled by the cognitive processes, in comparison to the millions of signals entering the brain. Sub-cortical brain structures like the thalamus, the hypothalamus and the amygdala take action particularly in the autonomic "taking-care of" the body to optimise the condition for survival. The amygdala, a structure situated on both sides of the middle-brain and in close contact with the hippocampus, our main memory structure, can be seen as a sentinel, initiating immediate actions for "fight or flight" if necessary. This is, of course, of great value for survival in immediate dangerous situations but maybe not so efficient in modern life when alerted too often in situations without "real" danger, causing stress and perceived threats for our health. The amygdala complexes are also highly involved in handling emotionally loaded signals (Damasio, 2005).

The fear reaction has been studied extensively to explain how the brain works in animal models down to the synaptic level, i.e. the connection between the neurons (LeDoux, 2003). It is now possible to explain in more detail the mechanisms of classical and contextual conditioning, sensitisation and habituation. The rapid development of imaging techniques opens possibilities for understanding what is happening in the different brain areas and why people react the way they do.

Most volatile chemicals in low concentrations are capable of eliciting "subjective" upper respiratory tract irritation; often several magnitudes lower than those concentrations used as TLVs in the occupational workplaces. Their odour, however, can often be perceived at concentrations far below those that will evolve into objective sensory irritation. The integrated sensory response can, therefore, be confounded by odour sensations besides a myriad of non-sensory factors such as expectations, experiences, attitudes, beliefs, and information about the risks from exposures (Distel and Hudson, 2001; Chen and Dalton, 2005; Wilkins et al., 2007).

The chemical impact on humans follows two sensory pathways, and most volatile chemicals activate both the olfactory nerve, which give rise to odours, and the trigeminal nerve giving rise to temporary burning, stinging, tingling or painful sensations in the eyes and the upper airways (Dalton, 2002; Cometto-Muniz and Cain, 1998).

To separate the influence of odours, a test of nasal lateralization is developed based on the fact that sensory irritation but not pure olfactory stimuli can be localised in the nasal mucosa (Cometto-Muniz and Cain, 1998). The neuropsychological background is that the sense of smell is not topographically represented in the human cortex like the other senses.

BIOLOGY IN FOCUS

Basic rules for survival during evolution has been to create a stable internal environment (homeostasis) and to protect against threatening external factors, whether it be tigers or microbes. The neural signals, barrier functions of skin and mucous membranes of eyes and airways and the development of the immune system are products of that development. The earliest part of the mammalian immune system, called the innate immune system, was initially developed to defend against most microorganisms such as parasites, bacteria and viruses and is still our basic defence “weapon”, although not always capable of taking care of new mutations of bacteria or viruses. Through the development of an adaptive immune system, which is available only for vertebrates and where the basic components are named B and T cells, the immune system can adapt to protect us against almost any invader by tailor-made efficient defence tools. Antibodies of different type, i.e. IgE and IgG, are formed by the B-cells in cooperation with the T-cells in complex pathways. However, like any defence weapon, the most advanced weapons can also be used against the host, a mechanism behind both “allergy shocks” (anaphylaxis) and autoimmune diseases. Environmental factors, i.e. microorganisms and organic dust, can stimulate the innate as well as the adaptive system, which forms the basis for the inflammatory potential of organic dusts (Sigsgaard et al., 2005).

Many moulds and some bacteria, which are often found in moisture-damaged buildings, have toxic potential. This means they have a potential to harm, even kill, cells in some target organs, which can be cells in the barriers, in the mucous membranes of the airways, or in different tissues elsewhere. For most agents, human data are not available and the hazardousness is assessed based on data from animal models or cell cultures. The evaluation of the toxic effects on humans, therefore, has large uncertainties. The dose-response relationship (as well as the unambiguous cause-effect relationship) is essential when evaluating the health effects.

Besides the neurological and immunological systems, the endocrine system is also involved in restoring the homeostasis. Both the sympathetic nervous system (which releases adrenalin and nor-adrenalin) and the hypothalamus-pituitary-adrenal axis (HPA), which releases cortisol from the adrenal cortex, are activated in stressful situations. Cortisol is spread by the bloodstream to various organs, including the brain. Habituation to psychosocial challenges seems to differ between different persons, mainly due to differences in the function of the HPA-axis (Schommer et al., 2003). Stress can aggravate the immune changes and it seems as if atopics may be more strongly affected than others. (Olgart Höglund et al., 2006).

PSYCHOSOCIAL FACTORS IN FOCUS

Many studies indicate that psychosocial factors play a significant role in indoor air problems at several workplaces. It is suggested that the psychosocial environment can aggravate the problems based on theories involving stress mechanism and seen as modifying factors between environmental factors and symptoms (Cox and Ferguson, 1994). The stress might be attributed to anxiety and fear in regard to the hazards in the physical environment but also to consequences of organisational changes. A problem management process perspective is discussed by Lahtinen et al. pointing to the need of good management practise to avoid buildings becoming chronically “sick” in spite of rational corrective measures (Lahtinen et al., 2004; Thörn, 2002). Follow-ups of personnel from some workplaces with indoor air problems indicate that the sense of coherence, as measured by Antonovsky´s sense of coherence (SOC) scale, might help to detect personal vulnerability in relation to suspected environmental stress (Runeson et al., 2003).

FINDINGS BASED ON EXPERIENCE AND RESEARCH

Classical conditioning as an explanatory factor

After the restoration of buildings with indoor climate problems, some people may report that their symptoms return as soon as they come back to the building, although the results of the indoor air measurements are obviously excellent. For some persons, the reaction can be instantaneous just by reaching the entrance of the current building. Obviously, the nervous system is involved, and this is, most probably, an example of classical conditioning, first described by the Russian physiologist, psychologist, and physician Ivan Pavlov in the 1890s. He observed that a dog salivated (unconditioned response) as soon as the dog saw the food (unconditioned stimuli). By combining this situation with an acoustic signal, a bell, (conditioned stimuli), he was able to show that after some trials it was possible to initiate salivation (conditioned response) just by the bell. The dog was conditioned to the sound. Experimental studies from Belgium show that subjects can easily be conditioned to unpleasant odours and even unpleasant mental images (Van den Bergh et al., 2002). Anxious subjects are easier to condition. This means that remaining odours after restoration or other factors similar to the conditioned stimuli can trigger the onset of symptoms and also physiological signs. However, applying an extinction procedure by presenting the odour a number of times without the negative stimuli readily eliminates the symptoms (Van den Bergh et al., 1999).

The biologic mechanisms of conditioning are known on the synaptic level and it is shown that the amygdala structures are involved. It is not possible to fear-condition without these structures. Just informing about such a possible mechanism can help people stay and reduce or eliminate the symptoms. By always leaving “dangerous” environments, the natural habituation process (also known on the synaptic level) will be disrupted and this is one of the hypothetical explanations as to why people with “new” entities, such as MCS (multiple chemical sensitivity) or “electrical sensitivity”, sometimes finally live without modern equipment in a cottage in the forest.

Another similar condition – context conditioning – is interesting. If we meet a tiger in our garden, the innate fear reaction will be alerted instantly but we can enjoy and admire tigers in the Zoo – well protected behind fences. It is shown that other nerve nuclei in the amygdala are involved and these nuclei are connected with both the hippocampus (our centre for memories) and the frontal lobes (Ledoux, 2003). If the risk communication process, discussed later in this paper, creates an area of trustful security, it is tempting to see this as an effect of this biological mechanism.

The need of a holistic perspective

A large state-owned institution was opened in November 1997. Before the end of that year complaints about indoor climate problems were reported and the employees related typical SBS symptoms to the indoor environment. A survey was initiated, verifying a high prevalence of complaints (dust and dirt, dry and stuffy indoor air), general symptoms and dryness symptoms from eyes, nose and skin. Technical measurements showed both chemicals and dust in the indoor air. It was suggested that this was mainly due to emissions from the new building materials and new equipment. Unfortunately, the proposed follow-up was never initiated until the complaints of the personnel reached mass media interest in the summer of 2001. A private company surveyed the institution by means of “sniffing” dogs, and concluded that the whole institution was seriously contaminated with mould. Clinical investigations were initiated including a standard skin prick test. Blood samples were collected and frozen down and stored at low temperatures (– 70^0 C). 75 % of the study group showed a positive skin prick test (based on the criteria of a positive test whereby at least one wheal had a mean diameter of at least 3 mm), which was a remarkable outcome. The physician commented that the employees were not themselves aware of being sensitised toward different allergens and his conclusion was that there seemed to be an increased sensitivity in the skin, because the positive histamine control was much larger than usually seen. The information given by the “sniffing dog” company was frightening and when moulds of the species Stachybotrys were found in two samples, the situation became impossible to handle and the institution was forced to close to enable restoring actions. The employees were spread to workplaces outside the institution. A follow-up questionnaire survey showed that the increased prevalence of mucous membrane irritation disappeared within some months.

The employees were followed after the restoration for years and no remarkable allergic reactions were ever seen (neither in the skin prick test and radioallergosorbent (RAST) test, nor in an increased prevalence of symptoms related to the indoor environment). In 2004, the frozen blood samples were analysed with the RAST technique, showing completely normal values and no positive test in the specific mould-RAST panel. This raises the question as to why there was an extraordinary result for the skin prick test, which is supposed to be an “objective” medical test.

Professor Zacharei and his research group in Aarhus, Denmark have shown that after hypnotising young students into different moods (happiness, sadness, anger) over a 15 minute period and, during this time, injecting subcutaneously a small amount of histamine, the skin reactions differed, with the skin reaction being larger during sadness (Zachariae et al., 2001). We also know that stressed persons can change the sensitivity in the skin by activation of the autonomic nervous system. In this case, the employees were probably stressed and scared. There are several components in the skin, not just plasma cells that can release histamine, but also substance P and some immune competent compounds that can be activated. Although the extraordinary outcome is still a mystery, it reveals for me just how closely related the body and brain are.

The importance of strategies and good risk communication

The perception of indoor air and related symptoms is by definition subjective and mostly collected by the use of questionnaires. Differences in the design of the questionnaire including the type of questions, the use of different recall periods and category scaling may explain some of the differences seen from study to study. By using standardised questionnaires these differences can be reduced and by creating large databases, efficient comparisons can be made using suitable reference values. In a practical situation, this is extremely valuable because it is both expensive and sometimes difficult to find a valid control group of suitable size. The standardised MM Questionnaires, developed in the 1980s, have been used in different indoor environments with problems (workplaces, schools, day care centres, hospitals, offices and dwellings) and also in large surveys in Sweden and Finland and as a basic instrument in many epidemiological studies (Andersson, 1998).

In practice, we seldom measure higher concentrations of chemicals or particles in the indoor air in problem buildings compared to buildings without reported problems (Bakke et al., 2008). However, people do complain and relate their problems to the building. It is little wonder that conflicts arise, people are frustrated and outraged, and such cases easily reach the newspaper headlines. In order to handle these situations we need a strategy. A WHO-strategy published in 1983 functions excellently in this respect (WHO, 1983). Through the combination of a simple walk-through and standardised questionnaires to structure the information of the occupants and to give access to relevant reference data, as well as the use of a management process proposed by Lahtinen et al., most problems can be solved efficiently (Lahtinen et al., 2004). We must be aware that people perceive risks differently depending on whether the risk is related personally to the individual or family, or is related to the public. Risk perception also tends to involve factors such as whether the risks are voluntary, fairly distributed and possible to control. Principles of basic risk communication should be used. These include finding out what worries people; explaining the reason for your assessment and the confidence you have in your judgement, involving laypeople in the assessment, and, most of all, accepting that people are worried and respecting their worries, even if the scientific evidence is inconceivable. To create trust and credibility is of the utmost importance in the risk communication process.

IMPLICATIONS FOR FURTHER STUDIES

In order to gain more knowledge about people's reactions in indoor environments, there is a need to i) refocus on specific symptoms, and ii) scientifically focus more on mechanistic studies (pathophysiology), i.e. identify cause-effect relationships and dose-response relationships. The evidence for a strong relation between body and mind are rapidly growing but has so far had little impact on the indoor air research. Theories and research tools in the areas of neuropsychology and medicine open up new possibilities to study why people react the way they do. Epidemiological studies have formed a basis for our knowledge of associations between indoor environmental factors and health effects, but the epidemiologic techniques have limitations when handling the complex exposure situations and unspecific and complex health outcomes (Thörn, 2002). Controlled experimental studies in climate chambers and animal test models will increase the possibilities to test hypotheses and minimise the usual conclusions of many studies finding significant results "indicating potential health effects".

In spite of limited "real" knowledge, we mostly know enough to handle indoor climate problems in practise, being aware of the diversity of susceptibility and reactions among the occupants.

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