HEALTH AND COMFORT IN BUILDINGS

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Summary

Buildings play a major role in a health perspective. The most important aspect of buildings is that they should provide a comfortable and healthy environment for

humans. The non-industrial indoor environment is the most important environment from a human health perspective. Allergies, airways infections, lung cancer etc. are associated with indoor air quality (IAQ) in such settings. The knowledge is limited with regard to causative agents in indoor air, but there is mounting evidence that the indoor environment, especially “dampness” and “inadequate ventilation” plays a major role from a public health perspective in the developed regions of the world. In the developing regions un-vented indoor burning of biomass has a major impact on the global burden of disease. The economic gains to society for improving indoor environments by far exceed the cost.

1. History of buildings and health

Regarding the inadequate ventilation of schools in Stockholm: "*Today we are, righteously, beginning to demand that persons working with sanitary matter should have not only technical, but also hygienic education"*. Elias Heyman. Professor of Hygiene at the Karolinska Institute, Stockholm, 1880.

Man’s origin is in the tropical or near-tropical parts of the world. Man’s spread into cold climates was accomplished in spite of his physiology and was possible only because of his invention of such things as clothing, housing and the use of fire. However, in houses and shelters it is not only the thermal climate that is changed. The climate shell also stops the free air movement. The dilution of pollutants from close-to-man pollutant sources is diminished. The environment within a shelter is thus always more polluted from sources such as humans and open fires, as it still is in many parts of developing countries, and today in developed countries from sources such as building materials, indoor activities, etc. than is outdoor air. This was and is the basis of the need for ventilation and for discussions on IAQ. Humans arrived to e.g. Southern Europe, and China a million years ago, but to America, northern Europe, Japan etc. only some 10 000 to 40 000 years ago, a time too short for major genetic changes. We are still as humans accustomed to a life on the savanna, in Africa!

As we spend most of our life (in many regions more than 90%) indoors, it is easy to understand that the most important environment in relation to our health is the indoor environment. During the breakthrough of modern hygiene, from mid 19th century, indoor environmental issues received much attention, as did the quality of drinking-water and the treatment of sewage (e.g. linked to plagues such as cholera and tuberculosis).

Ventilation comes from Latin "ventilare" meaning "to expose to the wind". The main purpose of buildings is to create a climate more suitable for persons and processes than the outdoor climate. Consequently, the main aim of building ventilation is to create an indoor air quality more suitable for persons and processes than what naturally occurs in the unventilated building, and to reintroduce the positive effect of being "exposed to the wind", i.e. to dilute and remove the pollutants that man himself, his activities, and the indoor surrounding produce.

Without ventilation, i.e. exchange of polluted indoor air with "fresh" outdoor air, any shelter quickly degrades. Provisions for ventilation have always been arranged consciously or unconsciously. Already, the Romans had ingenious solutions such as hypocausts, a kind of combined heating and ventilating system.

Throughout history man has known that polluted air may be detrimental to health. Greeks and Romans were aware of the adverse effects of polluted air in e.g. crowded cities and mines (Hippocrates, 460-377 BC), in spite of lack of knowledge on the functioning of the lungs or the breathing.

In The Bible it is acknowledged that living in buildings with dampness problems is dangerous to your health. The remedies needed were quite thorough (i.a. to get rid of all affected parts of the building).

Through the medieval era little new knowledge in this field appeared. The epidemiological findings of associations between health effects and working in certain heavily polluted premises (Ramazzini, 1633-1714), living in crowded cities, such as London (Arbuthnot, 1667-1735), and the sad history of many young chimney sweeps (Pott, 1778) shed new light on the importance of air pollution. Later on, the death of persons imprisoned in small room volumes (Baer, 1882), or the economic burden of the deaths of slaves from suffocation during transport over the seas gave evidence on the importance of ventilation in premises mainly polluted by man. That "bad" ventilation was not only a problem in more extreme situations was also acknowledged at that time. Gauger (1714) remarked that it was not the warmth of a room but its inequality of temperature and want of ventilation that caused numerous maladies. Bad air was held responsible for the spread of disease and for the unpleasant sensations that are experienced in badly ventilated rooms.

The general idea up to around 1800 was that breathing primarily was a way of cooling the heart - the substance of air was not required, only its coolness. But, it was also common knowledge that expired air was unfit for breathing until it had been refreshed (Wargentin, 1717-1783). The mystery of breathing was not solved until Priestley (1733-1804) discovered oxygen, and von Scheele (1742-1786) and Lavoisier (1743-1794) found that air consisted of at least two gases. The role of oxygen in breathing was pointed out by Lavoisier (1781), even though Boyle (1627-1691), and Hooke (1635-1703) 100 years earlier (1667) had found that the supply of air to the lungs was essential for life, and Mayow (1643-1678) had discovered that there was an exchange within the lungs between the air that was breathed and the body.

Especially the work of Lavoisier (1781) was important for understanding the human metabolism, including the quantitative association between oxygen consumption and carbon dioxide (CO_2) release. During the following half century it was accepted that the concentration of CO_2 was a measure of whether the air was fresh or stale.

Against the background of tuberculosis and other diseases known to be contracted in crowded places, John Griscom, a New York surgeon, vividly described the need for fresh air and pointed out bedrooms and dormitories as worst: "deficient ventilation ... (is) more fatal than all other causes put together" (Griscom, 1850).

Crowded rooms tend to be overheated and during this era, it was considered that the discomfort in such rooms was due to excessive heat or, in accordance with the view of Lavoisier, due to elevated concentrations of CO_2. Pettenkofer (1818-1901) started lecturing on hygienic topics in Munich 1847, and installed as the first professor in hygiene worldwide 1853 noted that the unpleasant sensations of stale air were not due merely to warmth or humidity or to CO_2 or oxygen deficiency, but rather to the presence of trace quantities of organic material exhaled from the skin and the lungs. He stated that "bad" indoor air per se did not make people sick, but that such air weakened the human resistance towards "jede art krankmachenden Agentien", i.e. in modern words acted as an adjuvant factor. In Pettenkofer's view CO_2 itself was not important, but could be used as an indicator of the amount of other noxious substances produced by man. Pettenkofer stated "jede luft als schlect und fur einen beständigen Aufenthalt als untauglich zu erklären sei, welche in folge der Respiration und Perspiration der Bewohner mehr als 1.0 p.m. (1000 ppm) Kohlensäure enthält und".." dass eine gute Zimmerluft, in welcher der Mensch erfahrungsgemäss längere Zeit sich behaglich und wohl befinden kann, keinen höheren Kohlensäuregehalt als 0.7 p.m. (700 ppm) hat" (Pettenkofer, 1858). He and a number of other authors of this time suggested 1000 ppm of CO_2 (including CO_2 from ambient air) as a limit value for an adequately ventilated room (700 ppm in bedrooms), including some margin for the use of oil burners for lighting.

A number of studies of ventilation in schools, theatres, homes, etc. were conducted with the concentration of CO_2 as a measure of ventilation rate. The first Swedish professor in hygiene, Elias Heyman (1829-1889) at the Karolinska Institute, made an extensive study of schools with different ventilation systems in Stockholm, including measurements of CO_2, air flow rates, air temperature in the room and outdoors, and notations on number of occupants in the room as well as of speed and direction of the wind outdoors. In schools without any ventilation he measured concentrations of CO_2 up to and over 5000 ppm, while he in schools with any kind of ventilation typically measured maximum concentrations of between 1500 and 3000 ppm. He concluded that not even one schoolroom was adequately ventilated. He also made an interesting comment on common complaints regarding "dry air" in a building with supply of heated air (up to 60* C), a sensation that he meant had nothing to do with the air humidity but rather was an effect of air pollutants drawn into the system from a neighborhood chimney. Parallel to the complaints of "dry air" there were complaints of mucousal and skin problems, i.e. a description close to today's sick building syndrome (SBS). Also "häufige Auftreten von Kopfschmerzen" among schoolchildren were believed to be caused by "verdorbenen Luft der Klassenzimmer" (Becker, 1867). Heyman (1881) also studied homes and concluded that we can not rely on "natural" ventilation if we want to live in "clean" air. Wallis (1845-1922) in the same manner studied theatres and restaurants. Pettenkofer and other researchers of this era, within the field of building hygiene, often stated that source control is a prerequisite for good hygiene "Ohne durchgreifende Reinlichkeit in einem Hause helfen uns alle Ventilationsvorrichtungen wenig".

In his textbook on ventilation and heating Professor Herman Rietschel at the Kgl. Technischen Hochshule in Berlin totally built on the views of Pettenkofer (Rietschel 1894, 1902). The textbook is in many ways up-to-date including its guidelines on outdoor airflow requirements, and dimensioning of both ”natural” and mechanical ventilation.

Beginning with the results of Pettenkofer a number of studies were conducted between 1880-1930 in search for evidence of the toxic effects of organic substances in expired air, the anthropotoxin theory (e.g. Brown-Séguard and d'Arsonval 1887). Since no proof of toxic effects could be found and since high concentrations of CO_2 as single pollutant caused no discomfort, the warmth of a crowded room together with smelling, but not toxic, body emissions were thought of as main sources of discomfort in rooms with bad ventilation (Flygge, 1905; Hill, 1914). Flygge (1905) wrote that the objection to an evil-smelling atmosphere was to be supported not on account of its poisonous properties, which had never been proven to exist, but on account of the resulting feeling of nausea.

Thus, ventilation was primarily a question of comfort and not of health. However, Winslow and Palmer (1915) found in a study of the effects of lack of ventilation upon the appetite for food, that there were substances present in the air of an unventilated occupied room which in some way, and without producing conscious discomfort or detectable physiological symptoms, diminished the appetite. In the experiments they controlled temperature, humidity and air movement. In later work Winslow and Herrington (1936) obtained the same results with heated house-dust taken from vacuum cleaners as source of air-pollution.

In their standard-setting work Yaglou, Coggins and Riley (1936) studied body odor in relation to ventilation rates. They stated that such odors, as a rule, are not known to be harmful. They recognized, though, that "Sensitive persons are occasionally affected in a pathological way by sitting in such rooms". Thus, again, ventilation was primarily a question about comfort. ".. occupied rooms should give a favorable impression on entering, taking into consideration such factors as odors, freshness, temperature, humidity, drafts and other factors affecting the senses". They showed that simple recirculation of air did not affect the odor strength and concluded that "from the standpoint of body odor, a room can be ventilated just as well with an outdoor air supply of 8 L/s/p as with a total supply of 15 L/s/p, about 1/2 of which is recirculated”. Recirculation is often desirable for adequate distribution and temperature control, but one of the disadvantages is that it smells up the ducts, fans, et. and unless the system is flushed frequently with clean air, higher air quantities will be needed to obtain satisfactory results". They also experimented with humidifying and dehumidifying of the recirculated air and found that both techniques and especially dehumidifying reduced the odor strength resulting in a reduced need of outdoor air supply for odor control.

Since the 1930's there has been little scientific effort within the field of ventilation - IAQ - health in non-industrial premises. Odor and thermal comfort were thought of as the factors relevant in setting guidelines for ventilation.

Historically, ventilation standards have been based on the assumption that man himself is the main source of indoor pollution, mainly body odors. During the last century, health issues have mainly not been involved, instead the classical measure of air quality has been the extent to which odor is perceived as acceptable by visitors directly on entry into the premises. This measure was used by Yaglou, and has in recent decades been developed by Fanger and colleagues (Fanger, 1988; Fanger at al., 1988). Fanger also, stresses the comfort aspect of indoor air pollution in stating "It is normally the perception that causes people to complain", but also "the perceived air quality ... may in many cases also provide a first indication of a possible health risk" (Fanger, 1992). Fanger has focused on the sensory load of pollution sources, besides persons, such as building materials, fixtures, fittings, furnishings and furniture.

After Yaglou's studies, the view on required ventilation levels were largely unchanged for a long time. The typical minimum value for general office spaces was 7.5 L/s/p of ventilation air, as recommended by the American Society of Heating, Refrigerating and Airconditioning Engineers (ASHRAE, 1977). As result of the oil embargo 1973, and the subsequent rice in the price of energy, requirements in non-smoking areas were reduced to minimum values of 2.5 (USA) and 4 L/s/p (Nordic countries), respectively. Lately, in response to increased interest in building hygiene, revised ventilation requirements have appeared with minimum values, for office spaces, raised to 10 L/s/p (USA) and about 11 L/s/p (Nordic countries). Today there is evidence for a need of higher ventilation rates.

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Bibliography

General

ASHRAE (2001). Handbook. Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bardana Jr EJ, Montanaro A. (1997). Indoor Air Pollution and health. Marcel Dekker Inc.

Boschi N (ed). (1999). Education and training in indoor air sciences. Kluwer Academic Publishers.

ECA (European Collaborative Action). (2000). Risk assessment in relation to indoor air quality. Office for Official Publications of the European Communities, Luxembourg.

IOM, Institute of Medicine. (2000). Clearing the air. Asthma and indoor air exposures. National Academy Press.

Maroni M, Seifert B, Lindvall T (eds) (1995). Indoor air quality. A comprehensive reference book. Elsevier.

Spengler J, Samet J, McCarthy JF (2001). Indoor Air Quality Handbook. McGraw Hill. (An up to date most comprehensive textbook on most aspects of IAQ and health)

Sundell J (1994). On the association between building ventilation characteristics, some indoor environmental exposures, some allergic manifestations and subjective symptom reports. Indoor Air, Supplement No2/94.

Sundell J (Principal author) (1999). Indoor Environment and Health. National Institute of Public Health, Stockholm, Sweden

Dampness
Bornehag C-G, Blomquist G, Gyntelberg F, Järvholm B, Malmberg P, Nielsen A, Pershagen G, Sundell J (2001). "NORDDAMP". Dampness in buildings and health. Indoor Air 2001;11:72-86. 1

Economy
Fisk, W.J. and Rosenfeld, A.H. (1997) "Estimates of improved productivity and health from better indoor environments", Indoor Air, 7, 158-172. (Errata: Indoor Air 1998, 8, 301.)

IAQ in the developing world
Smith KR, Liu Y. (1994). Chapter 7: Indoor air pollution in developing countries. The epidemiology of lung cancer. Samet J. NYC, Marcel Dekker: 151-184.

Smith KR, Samet JM, et al. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 55(6):518-532.

Smith KR (2000). National burden of disease in India from indoor air pollution. Proceedings of the National Academy of Sciences 97(24):13286-13293.

IAQ-guidelines
Andersson K, Bakke JV, Björseth O, Bornehag C-G, Clausen G, Hongslo JK, Kjellman M, Kjaergaaard S, Levy F, Mölhave L, Skerfving S, Sundell J (1997). TVOC and health in non-industrial indoor environments. Indoor Air 1997;7:78-91.

WHO, World Health Organization (1986) Indoor air quality research, Report on a WHO meeting. EURO reports and studies 103. Copenhagen: World Health Organization, Regional Office for Europe.

WHO, World Health Organisation (1987). Air Quality Guidelines for Europe. WHO Regional Publications, European Series No23. WHO, Copenhagen.

WHO, World Health Organization, (1989) "Formaldehyde", Environmental Health Criteria 89, World Health Organization, Copenhagen.

WHO, World Health Organization (2000). Guidelines for air quality. World Health Organization, Geneva.

Pets
Ahlbom A, Backman A, Bakke JV, Foucard T, Halken S, Kjellman N-I,M, Malm L, Skerfving S, Sundell J, Zetterström O (1998). "NORDPET". Pets indoors - A Risk Factor or Protection against Sensitisation/Allergy. A Nordic Interdisciplinary Review of the Scientific Literature Concerning the Relationship between the Exposure to Pets at Home, Sensitisation and the Development of Allergy. Indoor Air 1998;8:219-235.

Ventilation
ASHRAE (1989) Standard 62-89: Ventilation for Acceptable Indoor Air Quality, Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

CEN (1998) Technical Report CR 1752: Ventilation for Buildings: Design Criteria for the Indoor Environment, Brussels, European Committee for Standardization.

ECA (European Collaborative Action "Indoor Air Quality and its Impact on Man") (1992) Guidelines for Ventilation Requirements in Buildings, Luxembourg, Office for Publications of the European

Communities, Report No. 11 (EUR 14449 EN).

Seppänen, O.A., Fisk, W.J. and Mendell, M.J. (1999) “Association of ventilation rates and CO_2-concentrations with health and other responses in commercial and institutional buildings”, Indoor Air, 9, 226-252..

Wargocki P, Sundell J, Bischof W, Brundrett G, Fanger O, Gyntelberg F, Hanssen SO, Harrison P, Pickering A, Seppænen O, Wouters P. (2002) Ventilation and health in nonindustrial indoor environments. Report from a European multidisciplinary scientific consensus meeting. Indoor Air, Accepted..

Biographical Sketch

Dr. Jan Sundell received a Master of Science of Engineering at the Royal Institute of Technology, Stockholm, 1969. He received his doctoral in Medical Sciences at the Institute of Environmental Medicine at the Karolinska Institute, Stockholm, 1994.
Between 1969-1978, Dr. Sundell was with the National Board of Urban Planning and Building, Stockholm, responsible for building codes on ventilation, and indoor climate. He was then responsible for legislation on indoor climate and ventilation at the Occupational Safety and Health Administration of Sweden.
During the last 15 years he has conducted large epidemiological field studies on asthma and the home environment of children, and on SBS among office workers. Dr. Sundell has been also involved in Governmental inquiries in Sweden on Allergies, and Environments and Health, and has acted as chairman of Nordic and European interdisciplinary scientific reviews on indoor air and health, regarding VOC/health, Pets/allergies, Dampness/health, Ventilation/health, Indoor Particles/health, and Breastfeeding/allergies. He is expert advisor at the National Institute of Public Health, Stockholm on indoor environments and health. He received the Nordic INDOOR CLIMATE Award 1995, and the SCANVAC Prize 1999. Dr. Sundell is the Editor-in-Chief of the scientific journal Indoor Air.