3167

THE IMPORTANCE OF BUILDING AND POLLUTANTS INTERACTIONS BY THE DESIGN AND PERFORMANCE OF VENTILATING SYSTEMS

Ove Nielsen
National Building Agency
Danish Ministry of Housing and Building

Abstract

Ventilation has a vital effect on indoor climate, and even in earlier times, buildings were constructed to maintain some degree of ventilation. Indeed, the building legislation has included requirements concerning ventilation from the very start. However, ventilation has probably been regarded as necessary for maintaining stable combustion and preventing high humidity rather than as a criterion for a good indoor climate. In fact, the view is still heard - and not only in the ventilation branch - that a good indoor climate is purely a question of sufficient ventilation and that increased ventilation is the answer to practically all indoor climate problems. Today, we know that the problem of indoor climate is more complicated than that. By means of a number of examples, this paper shows that, together with ventilation, the design of buildings and installations and, especially, the building materials used, have a pronounced effect on the quality of indoor air.

The importance of building and pollutants interaction by the design and performance of ventilating systems

Design of ventilation systems for non-industrial buildings such as offices and dwellings used to consist of a simple calculation. In the case of offices, greatest emphasis was placed on keeping the air temperature and the odour concentration at an adequate, acceptable level, and in the case of dwellings, the emphasis was on keeping humidity at a sufficiently low level to prevent damage to the building. It is only in recent years that the problem of emissions has been taken into account as well. Today, every building regulations in some few countries contain requirements concerning building materials and pollutants which are directly related to the indoor climate.

In the temperate part of the world, housing ventilation generally used to consist of natural ventilation in one-family houses and mechanical ventilation in multi-storey housing.

In many instances, the mechanical ventilating systems operated whether the building was in use or not. Occupants had little influence on the air change because the airtightness of the buildings was not particularly minimized, and little interest was taken in the operating condition of ventilating systems. To put it briefly, ventilating systems operated until they broke down.

What was the indoor climate like in buildings in which the following factors were ignored:

- emissions from, for instance, building materials, furniture and detergents
- pollutants from the subsoil - radon, for example
- the tightness of the outer walls and of the structures against the soil
- the siting of the building in relation to major sources of pollution outdoors
- preventive maintenance and operating supervision.

If one takes a look at literature going back more than 15 to 20 years, one gets the impression that the indoor climate was not all that poor. No complaints of poor indoor climate can be found, and the need for research and legislation relating to the indoor climate does not seem to have been given very high priority.

There may be several reasons for this:

- occupants were not especially critical of the air quality
- perhaps they accepted a poor air quality as compared with other conditions
- perhaps they did not know to whom to complain. The few complaints that were received were not related to or compared with each other
- the air quality was not unsatisfactory.

The last point may be an important one - the statement that unsatisfactory air quality is a present-day problem of buildings is often heard and also widely subscribed to. The explanation given by those who adhere to this view is that the difference between good, old buildings and poor, modern buildings - in terms of indoor climate - is that modern buildings are tighter. To save energy, buildings are being made increasingly tight, and sophisticated mechanical ventilating systems must cope alone with what used to be taken care of by leaks and simple ventilating systems. The variety of building materials used in old houses was limited, whereas, today, thousands of different building materials are being used, each containing a large number of chemical components, which, with more and more sophisticated measuring equipment, we are becoming exceedingly good at clarifying, although we still do not know their precise effects.

I do not contest the fact that building customs and the supply of building materials have changed. I am convinced, however, that there were also cases of an unsatisfactory indoor climate in the old days. I have, for instance, seen a medical report, published in 1807, by Dr. Heinrich Callisen, a Copenhagen doctor and titular Councillor of State, complaining about the indoor climate and the diseases it caused in the inhabitants of the multitude of houses built at that time (in 1795, a huge fire broke out in Copenhagen, destroying a large part of the city, and, in 1807, the British bombed the city, destroying many more houses).

So, explaining the causes of indoor climate problems is not a simple matter of distinguishing between new and old housing.

A small Danish survey concerning the content of organic solvents in the air in 14 rooms showed no correlation between the concentration of solvents and the age of the respective buildings. Naturally ventilated buildings had a higher concentration of solvents than mechanically ventilated buildings (the air change was not measured).

In a major Danish study of the indoor climate, the so-called town hall study, more than 3,000 persons in 13 town halls stated their opinion about the indoor climate in general and underwent certain health tests, the indoor climate was measured, and the buildings were assessed. No correlation was established between discomfort caused by the indoor climate and the ages of the respective buildings (which were between 1 and 80 years old). No correlation was found, either, between the air change, the ventilating system used, the CO_2 concentration, and the discomfort.

So, when considering the question of discomfort caused by the indoor climate, and ventilation, no simple conclusions can be drawn, such as 1) the more ventilation, the smaller the discomfort, or 2) it is not a question of how much pollution is emitted by, say, building materials, but of the amount of ventilation.

It is important that building materials, buildings, and ventilation, be viewed holistically.

Tighter buildings

The basic air change, defined as the air change in a building whose windows and inlets and outlets are shut and whose ventilating system is not in operation, has been measured in many studies in many countries. Requirements concerning tightness are easier to administer legislatively and in contracts, and in recent years, some countries have introduced legislation concerning the tightness of buildings to save energy. As regards the indoor climate ,there is no reason to object to a reduction of any air change that exceeds what is necessary.

The studies show that this has been achieved: the basic air change has been reduced from more than approximately once per hour to approximately 0.2 times per hour. And, not least, the studies show that it has been proved possible, by means of building and structural innovations in special test houses, to reduce the basic air change still further. Some studies have attempted to demonstrate a correlation between the basic air change and the tightness of a building, measured in terms of certain standardized over-pressures and under-pressures. However, this task is of little practical interest and is really not feasible at all. A few studies have set out to establish whether it is possible to maintain a low basic air change (or high tightness), or, in other words, to ascertain the lifetime of structural measures to tighten a given building. Even fewer studies have examined whether the population knows that, whereas they previously did not have to do anything to achieve air change, since this happened automatically, they themselves must now bring about the air change because of the tightness of modern buildings. This is of far greater importance to the indoor climate than whether structural measures to tighten a building are effective for 5 or 10 years.

One means of reducing the basic air change is by using large quantities of joint filler in all joints, of which there is a multitude in modern, industrialized buildings. Joint fillers can influence the air quality in another way as well: like paint, for instance, there is considerable emission from them immediately after they are applied. But for how long does the emission continue? Some recent cases in Denmark relating to the indoor climate show that the emission from joint fillers can last for more than one year.

At the same time, these cases proved that the need for joint filler indoors is largely determined by the design of architectural details. Many modern architects prefer visible joints round inside doors to placing architraves on door frames. If, in addition, the architect requires that the same paint be applied on top of the joint filler as is applied to the walls, he has determined both a larger-than-normal consumption of joint filler indoors and the type of filler to be used.

So, tightness requirements, architectural details, and colour schemes, play a major part in determining the final air quality. The solution is not to stop making such requirements but to take the initiative for the introduction of a scheme of informative labelling for joint fillers or for building materials in general regarding health, in line with existing labelling regarding, for instance, the adherence, elasticity, application of paint, etc.

Supply of outdoor air

A great deal of effort has gone into the development of inlets for mechanical air supply. Large quantity of air per inlet, small quantity of air, large mixing with room air, small mixing, higher inlet temperature than room temperature, lower inlet temperature, inlet into high-ceilinged rooms, inlet into low-ceilinged rooms, etc. So, in this case, I estimate the need for further product development to be limited. As regards house ventilation, which in most countries consists of mechanical or natural exhaustion from kitchen and bathroom and inlet of outdoor air through inlets in the outer wall(s) of living rooms rather than of a mechanical supply of air, the need for product and system development, in my opinion, is great.

A number of functional requirements, based on the indoor climate, can be made to outdoor-air inlets. For instance:

- the inlet must supply 6-9 l/s without producing draught in the living area
- the inlet must not reduce the facade's sound insulating capacity
- it must be easy to shut the inlet in case of extreme outdoor conditions
- the inlet must be easily removable for cleaning.

Only a few outside-air inlets on the Danish market fulfil these requirements. Besides, there is a great risk that outside-air inlets that can only be used for part of the year without impairing the indoor climate will not be used at all and will thus result in poor air quality.

Besides the need to develop the outdoor-air inlet itself, I consider that there is also a very real need for studies concerning the possibilities for air distribution in homes and especially for supplying air to bedrooms. So I would also indicate product development of air-transmission components.

In connection with outdoor-air inlet, another question requiring attention is whether supplying outdoor air via inlets in outer walls can be used in all circumstances and, if so, whether we should then impose restrictions on the siting of new buildings. In heavily trafficated streets, car exhaust fumes are a serious source of pollution, giving rise to the question of whether outdoor-air inlets can be used in the ground-floor walls of new buildings erected in such streets or whether a balanched mechanical ventilating system should be required so that the air intake can be placed above street level.

Balancing, operation and maintenance

Both for residential buildings and other non-industrial buildings, a large, well-developed and skilled ventilation industry offers plenty of methods of controlling air change by need instead of on the basis of the outdoor conditions, and with proper running costs, thereby obviating the problems outlined above regarding the use of outdoor-air inlets and mechanical exhaustion.

However, I cannot concur directly in the growing tendency to believe that the more sophisticated the ventilating system that is installed in a building, the fewer indoor climate problems there will be throughout the lifetime of the building. There are many reasons for this tendency, and I certainly cannot just blame the ventilation industry. Everyone involved in a construction project, including the end users, must do their part if the building's ventilating system is to work as intended and continue to do so.

Ventilating installations must be checked and adjusted so that all air inlets and outlets are supplied with the right quantities of air. The automatic regulating equipment must be balanced, and both the ventilating installations and the automatic controls must be regularly maintained, cleaned, adjusted, renovated, and replaced as necessary, throughout the lifetime of the building.

I know of Norwegian, Swedish and Danish studies that have revealed faults and incorrect, usually too small, quantities of air, even in completely new ventilating systems, and measurements on installations that are just a few years old show that the total output is almost always too low. Similar findings have undoubtedly been made in other countries. Studies on the need for cleaning ventilating systems with a view to determining where dirt settles, the proper equipment for cleaning, etc., are few and far between. In my previous post at the Danish Building Research Institute I have, on a couple of occasions, measured the effect of cleaning two types of ventilating systems, in a block of flats and an office building. After cleaning, there was a 50-100% increase in air production.

Professor P. O. Fanger, of the Technical University of Denmark, has introduced a new indoor-climate unit, an olf, which you have probably heard about. Fanger's first field investigation concerning this new unit showed that, for some types of ventilating systems, the subjectively rated air quality was lower with the ventilating system in operation than without it.

So, dirt in ventilating plant not only reduces the air change, but apparently itself causes pollution and thus a poorer indoor climate. This, too, indicates a need for product and design development, for example:

- installations that do not retain dirt in unintended places
- installations designed and built for easy cleaning
- cleaning equipment for ventilating systems.

A question such as the accessibility of the ventilating installations (or heating installations, for that matter) is largely settled on the drawing-boards of the architects and engineers designing the building. The less accessible an installation is, e.g. behind a big, heavy hatch at a height of 5 m or on the roof, the less preventive maintenance the daily operating personnel will be expected to perform.

Emissions

Peter A. Nielsen, of the Danish Building Research Institute, has classified building materials in three groups on the basis of gas emission/particle emission criteria. It appears that the problem of emissions from building materials is not limited to new buildings, and to such emissions must also be added the pollution from actual use of the building.

The first group of building materials contain a free content of pollutants - a kind of surplus in the material. This group includes formaldehyde from the urea-formaldehyde glue used in chipboard. Emissions are mainly the result of diffusion processes. Pollutants from materials in this group contribute particularly to poor air quality in the first period a building is in use.

The building materials in the second group also contain pollutants, but in bound form, for example mineral wool fibres from ceiling linings containing mineral wool and, again, formaldehyde from urea-formaldehyde-glued chipboard. In the previous case, the culprit was excess formaldehyde in the boards, which can be avoided with proper production methods, whereas in this case, the formaldehyde is a chemical component of the glue, and emission is caused by several different processes, e.g. wear, decay, dissolution, and ageing. For instance, the formaldehyde in the glue will be released if the glue dissolves under certain conditions as regards air temperature and relative humidity. In principle, in the right - or perhaps I should say - wrong conditions, materials in this group can emit pollutants to the indoor air throughout a building's lifetime.

The third group comprises building materials that do not themselves give off pollutants but that can deposit/accumulate pollutants from other sources and then release them again later. One only has to think of one's own sitting-room the morning after a party, stinking of tobacco smoke even though the ashtrays were emptied as soon as the guests left. The principle is applied in, for example, range hoods without an outlet, for which a charcoal filter is used instead, and in the USA, replaceable wall panels (paintings?) are used to adsorb NO_x from gas combustion.

Pollutants can be emitted to the room air through a variety of processes, adsorption, absorption, diffusion, dissolution, and physical activity. Materials in this group, too, can affect the air quality throughout the lifetime of a building, but unlike the other two groups of building materials, the effect from materials in the third group can be both negative and positive.

In the Danish town hall study mentioned earlier, a relationship was found between indoor climate discomfort and the area of hairy surfaces in the building. Both this and the aforementioned problem of dirt in the ventilating installations and the effect on the quality of the indoor air can presumably be assigned to this third group of building materials with deposition effect.

The problem concealed within the title of my lecture, the importance of building and pollutants interactions to the design and performance of ventilating systems, which was given to me by the conference's scientific committee, becomes very clear in connection with the account of these pollution mechanisms.

For the problems mentioned earlier, I have been able to indicate certain needs for product development and thus do my part to satisfy the conference's wish for as concrete suggestions as possible in order to reach the goal of creating possibilities for building healthy buildings. However, with regard to the problem now touched upon - that of emissions - I must stress particularly the need for further research and investigation aimed at extending our knowledge in this very important area.

When a ventilating system is in operation, certain pressure conditions are created in the building, usually a slight over-pressure in relation to outdoors, on which changes in the barometric pressure are superimposed. In ducts for incoming air, there is some over-pressure when the ventilating system is working. When it is not in operation - for example, outside working hours, the pressure conditions change completely, both in the rooms and in the ventilating system. Could this, perhaps, have an effect on the emission by hairy surfaces of adsorbed pollutants?

When we look at the thermal indoor climate, we know that heavy building materials - concrete, for example - can have a good, equalizing effect on the temperature of the air and that a ventilating system with a relatively small output and without mechanical cooling can give a good, thermal, indoor climate more cheaply and better than a system with a big output and mechanical cooling provided the system is in operation 24 hours a day, so that the low night temperatures are utilized. Should ventilating systems be required to operate around the clock in order to keep the pressure conditions stable and in this way exploit the deposition effect to bind pollutants to certain building materials?

Similarly, the use of ventilation ducts with hairy inside surfaces can be expected to reduce particulate pollution. Some of the particles not retained by the filter will be retained by the hairy duct walls. However, quite apart from the big problem of how to clean such ducts, some Danish studies indicate that if we use ventilation ducts made of mineral wool, the ducts themselves will cause pollution in the ventilated rooms in the form of mineral wool fibres. So, here, it seems a really bad idea to make use of the deposition effect.

There are other examples, too, that show that if we do not consider buildings, pollution and ventilation holistically, we shall find that an apparently good solution to a problem is, in fact, a very bad solution that actually aggravates the original problem or creates an entirely new one. An example: the principal source of radon is usually the subsoil, so radon penetrates buildings through gaps in the interface structures. When trying to remedy a radon problem in an existing building it is sometimes difficult to tighten the interface structures. An alternative is to increase the ventilation. As the radon problem is biggest in one-family houses, which, as mentioned earlier, are mainly ventilated by exhaustion from the kitchen and bathroom, combined with outdoor-air inlets in the sitting-room and bedrooms, increasing the ventilation here will most likely imply increasing the quantity of air exhausted, for example by installing a mechanical exhaustion unit if the house does not already have one. However, there are examples of this method of increasing the ventilation having resulted in greater under-pressure and thus in a greater radon penetration, creating a greater concentration of radon.

Installations that affect each other

During combustion, a number of pollutants are created that are normally removed through flues in chimneys from fireplaces, wood-burning stoves, and central heating boilers.

In Denmark, a type of boiler with an atmospheric burner has come onto the market since the introduction of natural gas. The thermal operating pressure is low, and in certain particularly unfortunate circumstances, the outside conditions can cause the smoke to "backfire" down the chimney. In order that this does not result in the flame getting blown out and thus in unstable heating, the boiler is equipped with a so-called draught-breaker, which ensures that smoke is led out into the boiler-room instead. From an indoor climate point of view, it would be better for the flame to go out than for the smoke to be able to get into the house. In that event, the problem would probably have been known today instead of me having to say that I do not know how widespread the installation is in Denmark or other countries and that I do not know how big a pollution problem it presents. However, as buildings - and here we are talking about one-family houses - are being made more airtight than before and have many air-consuming installations - e.g. range hood, mechanical exhaustion in the bathrooms, tumble-drier, drying cupboard, and fireplace, all of which aggravate the problem, I would think that we have here a far from minor indoor climate problem, and it is due to the fact that buildings, installations, and outdoor conditions, affect each other. However, the use of kerosine heaters and other heaters without a flue would give rise to even greater indoor climate problems.

20-30 years ago, indoor climate was an unknown concept. Today, it is an everyday expression. Unfortunately, it has become this mostly because some people are exposed to a poor indoor climate, and it is these cases that are written about and read about in the press and that are pinpointed in lectures, seminars, etc., presumably on the grounds that we can learn from the mistakes of others. However, this negative coverage of the indoor climate can, perhaps, be used positively for a definition of a good indoor climate: it is not heard, nor felt; it does not cause discomfort, and it is not mentioned in the media. More resources than ever before are being allocated to tackling the problem of indoor climate. Many scientists are working within this field, and the legislation covering it is increasing in step with our growing knowledge. The indoor climate is a complex made up of an incredible number of parameters and involving many different disciplines and trades. The sub-topic, air quality, also deals with complicated interactions between chemistry, gaseous and particulate pollutants, building materials, ventilation, design, and components, buildings, and use of buildings. Each of these topics is in itself large and can seem unsurveyable - and, of course, it does not simplify matters to have to deal with the topics not separately but as parts of a whole, called air quality.

Good ventilation is quite clearly a prerequisite for good air quality, but it is not the only criterion for it.