Adjusting Airflow in Office Buildings According to Outdoor Temperature

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Ventilation air flows in Swedish office buildings are normally designed for the summer cooling case. Much higher air flows are needed for this case than during the heating season, when only air flows satisfying from an hygienic viewpoint is necessary. Higher air flows are only needed during short time periods.

The purpose of this study was to investigate how the indoor climate in offices, where the air flows have been designed for cooling needs, is affected by varying air flows by season. This was investigated using test operations where air flows in different types of offices were reduced. The studied parameters included measurable factors of the indoor environment as temperatures, carbon dioxide, throw of the air inlets etc., together with the perception of the indoor climate among office workers. Therefore, questionnaires have been used in parallel with the physical measurements.

The results showed good possibilities to reduce air flows during a major part of the year. Apart from reduced use of electricity and heating energy, there are also possibilities to improve the indoor climate. This was supported by the results of the questionnaires. Problems with noise, draught, and dust can be reduced. The indoor relative humidity level was slightly increased in winter, which reduced the complaints on too dry air.

Introduction

The purpose of the "general ventilation" is to transport away the indoor pollutants, including excess heat from people and equipment, as quick as possible from the ventilated space. Excess heat is thus considered as a pollutant. It is important to note that the purpose of the ventilation in offices in many cases is different between summer and winter. The demand on the ventilation systems are therefore also different for different parts of the year. The true perception of the indoor climate depends on many different factors. Some of them could be measured directly by technical measurements while other factors are very hard to individually quantify.

Today, ventilation technology is often not used properly, in spite of advanced and well-developed components. The reasons for this are several, but one major draw-back is the lack of knowledge on how ventilation systems work in practice and how the indoor environment varies with operating conditions. It rarely is considered that the need for ventilation air is dependant on type of activity, building technology, outdoor conditions, etc.

Because the sizing of ventilation systems in office buildings often is a compromise between summer and winter operating cases, the systems are poorly used during a large part of the year. In summer, sometimes the air flow has to be increased for better cooling and in winter, without cooling load, the flows can be reduced. With this concept, the indoor climate can be improved both in summer and winter. During the winter, potential noise and draught problems can be reduced and the relative humidity increased. During the summer, a heavy building construction can be used together with the ventilation air flows, to even out the cooling load. This may result in a substantial reduction in operating costs.

The purpose with this study is to investigate different operating strategies and possibilities to optimise ventilation air flows in offices during the heating season by full scale testing in Swedish office buildings. More specifically, the effects of a reduction in ventilation air flows on the indoor climate have been studied. Three existing office buildings were involved, where air inlets and ducts are designed for relatively high air flows. The important question to answer is how the ventilation efficiency, thermal comfort and indoor air quality are influenced by different air flows.

The study was performed during the years 1992 and 1993. The summer case was not considered in this study.

Evaluation Methods and Measurements

The effects of reduced air flow have been studied by technical measurements and questionnaires at test operation with reduced flow as well as at design flows. The measurements were made both momentarily and continuously. The continuous measurements were performed for five working days and a weekend overlapping the momentary measurements. The change in air flows was performed about mid-week to more clearly see changes in the indoor climate. The results primarily give a picture of how the perceived and directly measured indoor climate is influenced by the different air flows. It should also be possible to compare how the measurements and the questionnaires coincide. The results could also serve as guidelines for ventilation air flow design when remodeling similar ventilation systems.

The design flows are 25 to 40 l/s per person with a maximum deviation of ±20%. During test operation the air flows were reduced to the minimum level of 8-10 l/s per person, as recommended by the Swedish Workers Protection Organization to avoid, among other things, excessively high CO_2 levels. These relatively low air flows assume that other pollutant sources are under control.

The outdoor temperature at the time of the measurements varied between -14°C to +10°C, which included about 90% of the duration of outdoor temperatures for the heating season in Stockholm.

The following parameters, that directly or indirectly affects the indoor climate, were measured: Air exchange, carbon dioxide, temperatures, relative humidity and total volatile organic compounds. The concentration of these parameters are also influenced by how the air is supplied.

The resulting effect of a change in ventilation air flow is best “measured” by the human response, which could be possible to evaluate by properly made questionnaires.

Air Exchange

The ventilation systems in this study are designed for mixing ventilation. If air flow is lowered in such a system, parts of the room could obtain more like a plug-flow air flow pattern. If this takes place in the living zone, the air change efficiency can be increased. Also, if the ventilation air temperature can be lowered because of reduced draught, the air change efficiency can be further increased as a consequence of reduced flow.

One hypothesis for this study was that the demand on air supply is less critical if mainly airborne pollutants are to transported away from the room than if the purpose is to cool (or heat) the room with the ventilation air. Therefore, air inlets designed for cooling should also work satisfactorily at lower air flows. If this hypothesis proves to be true, great possibilities to increase the efficiency of ventilation systems exist, especially in offices.

The air change efficiency has been determined by tracer gas tests in offices before and after the air flows have been reduced. Concentrations were measured in several points in the rooms and complete mixing was compared to no mixing tests. The throw lengths of the air inlets and convection currents were examined by air velocity measurements and smoke tests.

Carbon Dioxide Concentration

The carbon dioxide concentration is one of the parameters correlating with perceived indoor air quality. The concentration is basically a measure of airborne pollutants caused by people and determines the lowest level of air change rate. Temperature conditions and other indoor pollutants can increase the demand for ventilation air.

Concerning office spaces, we feel that the carbon dioxide levels are not critical, because the room volume per person normally is large and even more if the door is open as substantial air exchange can take place through it.

Both the actual concentration and changes in concentration are important parameters in how well the room is ventilated. This makes continuous measurements important. The duration of periods with high concentration is of interest. Daily averages, i.e. between the hours 8-16, as well as 15-minute averages have been studied.

The concentration was measured 1.6 meters above the floor in the living zone.

Temperatures

The temperature gradients were measured vertically, which gives an indication of how well the air in the room is mixed. Temperatures were measured 0.6 meters from outer (inner) walls in three levels; 0.1, 1.1, 1.6 m above the floor. The point 1.6 m above the floor in the living zone is the reference point were also CO_2, relative humidity and in some cases equivalent temperature were measured.

The supply air temperatures were measured at the air inlets and with the same intervals as the other temperatures. As the supply air temperatures possibly can vary with air velocity in the ducts, they are compared with outdoor temperatures. In some cases, the surface temperatures on windows and the supply and return water temperatures of hydronic radiators were measured. Outdoor temperatures were also measured.

The thermistor sensors have an inaccuracy of about ±0.2°C. The group of sensors were also inter calibrated with each other before each measurement.

Relative Humidity

The combination of low moisture load and high air flow in normal offices makes the indoor air very dry during the winter period as the outdoor air contains very little moisture. If the air flow is decreased, the relative humidity is increased. As the moisture load is low, the a substantial reduction in air flow is required to detect an increase in the indoor relative humidity.

The sensor for relative humidity was placed at the same spot as the CO_2 sensor and measurements were taken during the same periods. The inaccuracy of the sensor was ±5%.

The calculated variation in relative humidity and CO_2 concentration with the specific air flow at indoor temperature 72°C, outdoor temperature 0°C, outdoor relative humidity 85%, and indoor moisture production 3 g/m^3/h is illustrated in Figure 1.

Volatile Organic Compounds

The VOCs are emitted from organic substances from building and furnishing materials, but also from human activities. The VOCs are difficult to measure separately, so the total VOCs - TVOC concentration often is measured. An increase in air flow reduces the concentration of TVOC if the outdoor TVOC concentration is lower. There is, however, not a linear relationship between air flow and concentration, which among other things could depend on the fact that the emissions are increased by the increased air flow (Ekberg 1992).

A direct consequence of high concentrations of VOCs is throat irritation. The degree of irritation in relation to the concentration can be found in Mölhave 1986. In this study, no throat irritation could be found at concentrations below 0.16 mg/m^3.

The VOC concentrations indoors and outdoors were measured in the Yrket building at normal and test operation in a room with closed door (4 samples total) by using adsorption tubes and gas chromatography. The chromatograms are compared to measurements outside and to a reference library from several years of measurements of indoor air VOCs.

Questionnaires

An efficient way to obtain a measure of the perception of the indoor air quality is to let the occupants answer a questionnaire where they describe their perception of the indoor climate, what symptoms they have and if they think the symptoms are created by the actual building. The questionnaire follows the "Örebro" method and consists of about 30 questions (Andersson and Strid, 1991). Their

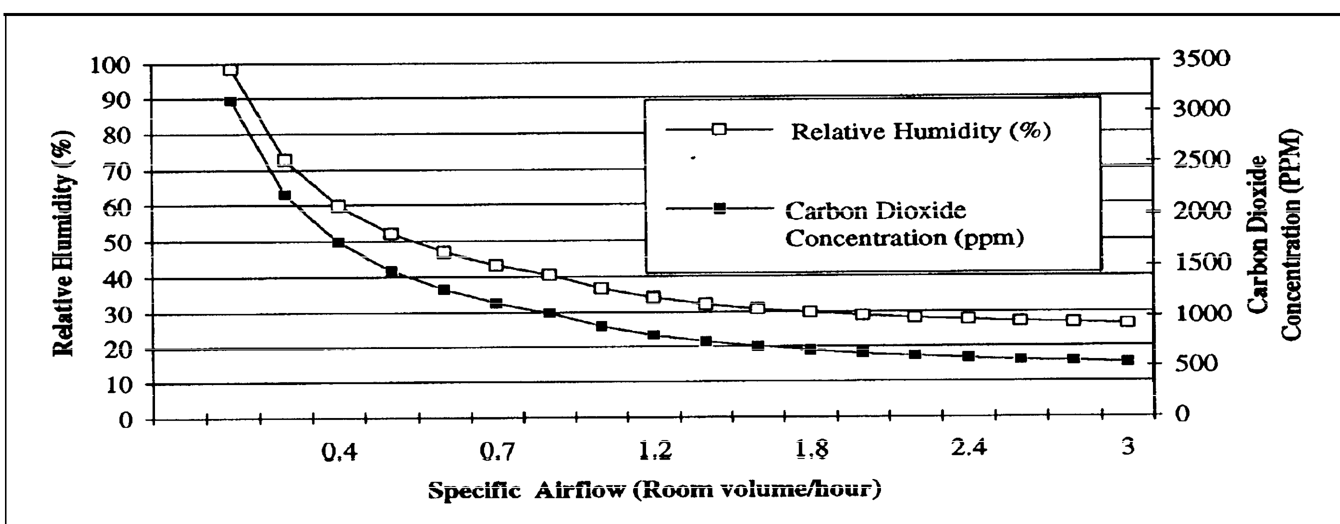

Figure 1. Calculated Variation in Relative Humidity and CO_2 Concentration with the Specific Air Flow

answers were compared to answers from buildings without indoor environment problems. Differences from the reference buildings point out technical malfunctions in the building. By also comparing with technical measurements, potential problems could be quantified.

For this study, the questionnaires were used partly to establish the buildings status compared to the “healthy” building and partly to evaluate the effect of lowering air flows on the perception of the indoor climate. The purpose is to make a rough mapping of the indoor climate where simplicity was of higher priority than to obtain all the details. When comparing between different operating modes, it is important to note other differences, as e.g. time of year since fatigue could be perceived differently in spring and fall. The relative humidity also varies with season.

The Office Buildings

The chosen office buildings represent a large part of the Swedish office building stock. They were built between 1965 and 1984. Some basic information on the buildings is given in Table 1. The ventilation air flows in these office buildings are designed for summer cooling. Some comparison data for the ventilation systems are given in Table 2.

Table 1. Some Basic Information on the Chosen Office Buildings

Building	City	Year of Construction	Floor Area, m^2
Yrket	Solna	1982	11,319
Kroken	Uppsala	1984	4,046
Romben	Sollentuna	1965	1,500

Figure 2 gives a plan of one of the office modules including measurement points. Some data on the measured offices are given in Table 3. The number of office workers was less than 0.1 person/m^2 for all measured office modules, Normally, the office door is left open.

The supply air in the Yrket building enters the room through the back wall with a temperature of about 21 “C. The throw length at normal flow is between 3-4 meters. For reduced flow, the throw length is 1-2 m. The exhaust air is drawn through the back wall.

The supply air in the Kroken building enters the room through the back wall with a temperature of about 20°C. The throw length at normal flow is between 2-3 meters. At reduced flow, it is reduced to less than 1 m. The exhaust air is drawn through the back wall.

The supply air in the Romben building enters through a window unit, which also can be used for both heating and cooling. The temperature is about 20°C. The throw length after reduction is less than 1 m but the mixing is improved by the stack effect from the heater in the window unit. The exhaust air is taken through the back wall.

Results

Indoor Environment Problems

The results from the questionnaires are based on 99 answers, which corresponds to 65% reply frequency. The sample is too small to draw any statistical conclusions. The purpose of the questionnaires was to see if any major changes in the indoor climate occurred at the test operation periods with reduced ventilation air flow. The results give an image of the general conditions in the offices and show that the investigated offices could be regarded as healthy compared to the reference material put together by the Clinic of Workers Health at the Örebro regional hospital.

Table 2. Data on the Ventilation Systems for the Office Buildings

Building	Design Flow, l/s·person	Total Pressure, Pa Supply/Exhaust	Specific Efficiency kW/m^2s	Yearly Operation, h
Yrket	20-24	800/600	4.5	2600
Kroken	25	500/350	2.8	2600
Romben	40	450/230	1.7	4000

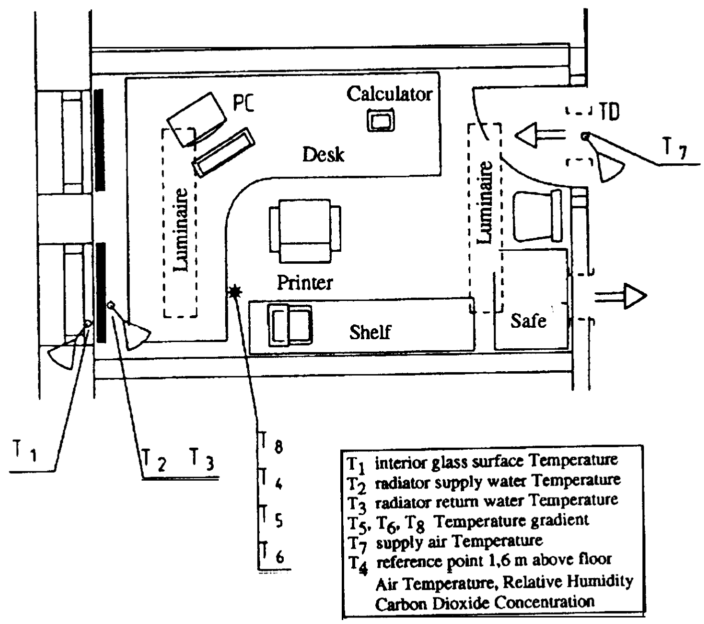

Figure 2. Plan of One of the Office Modules Including Measurement Points and Electronic Office Equipment

The general deviation from the reference material concerns complaints of dry and "stuffy" air. On the other hand there were very small remarks on noise, draught, static electricity or too high room temperatures. In all cases, the complaints of dry air seem to be reduced during test operation. Complaints of stale air were reduced in two offices during the tests.

There were also factors that changed differently. Inconveniences of dust and filth were reduced in the Yrket building and increased in the Kroken building. Complaints of irritated eyes were increased in the Romben building and reduced in the other offices. These complaints probably depend on long work time at computer terminals. This assumption is partly based on the fact that the lower noise level from the ventilation system during test operation is not seen from the questionnaires. The noise level is dominated by sound from the office equipment.

In the Romben building, the complaints of too low and varying room temperatures have been reduced at reduced air flow. Also complaints of odours and dry air have been somewhat reduced.

In the Yrket building, complaints of draught disappeared at the reduced air flow. Also complaints of dry air were reduced. These results seem likely considering the measured air flow pattern and moisture conditions. It is worth noticing that the inconveniences from dust, filth and stale air are also reduced at reduced air flows. This could possibly depend on the higher relative humidity. The results from the questionnaires at normal and reduced air flows can be illustrated by a circle diagram, as shown in Figure 3.

In the Kroken building, there was a tendency towards increased complaints of fatigue and headache at air flows

Table 3. Data on the Office Modules

Building	Area m^2	Ceiling height	Volume m^3	Window area, m^2	Internal heat load, W
Yrket	8.7(2.3·3.8)	2.6	22.7	1.7	550
Kroken	10.7(2.9·3.7)	2.6	28.0	1.6	370
Romben	10.8(2.4·4.5)	2.7	29.0	1.4	475

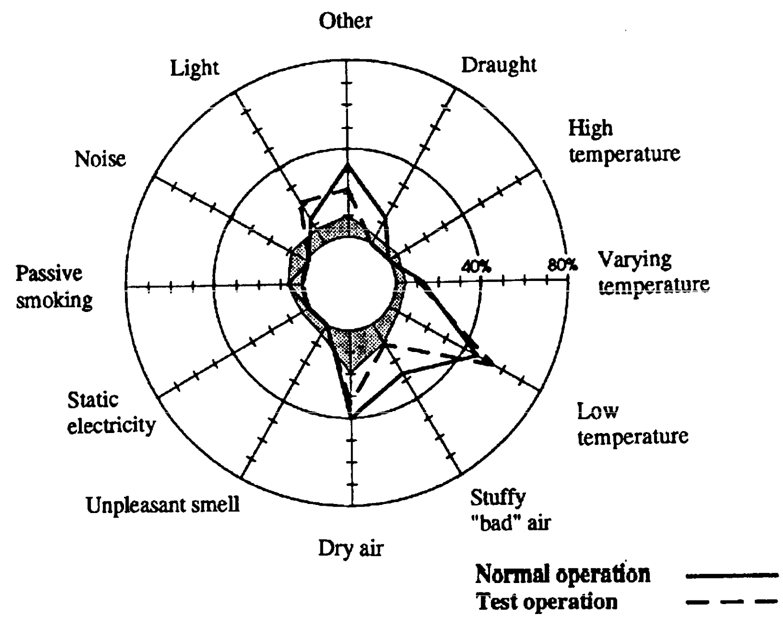

Figure 3. Results from the Questionnaires at Normal and Test Operation in the Romben Building. The radial axis show percentage dissatisfied.

lower than 10 l/s per person. For this case, hoarseness and dry throat complaints were increased, which could imply that the occupants were exposed to some infection. If this also could be the reason for increased fatigue, it could not be seen from this material. The risk of undesired circulation air should also be considered. The return air damper was closed during the investigation period, but questionnaire answers and measurements on relative humidity implies that circulation air existed during some periods.

In total, the perception of the indoor climate has not been worse at reduced air flows. If the high summer air flow is maintained the whole year, a risk of increased inconvenience of too dry air exists. If the air flows are reduced below the recommended level for hygienic reasons, 10 l/s per office module, the risk of fatigue and headache increases. This means that if reduced air flows are to be applied, ventilation systems have to be well adjusted so that the hygienic air flows are obtained for all parts of a building.

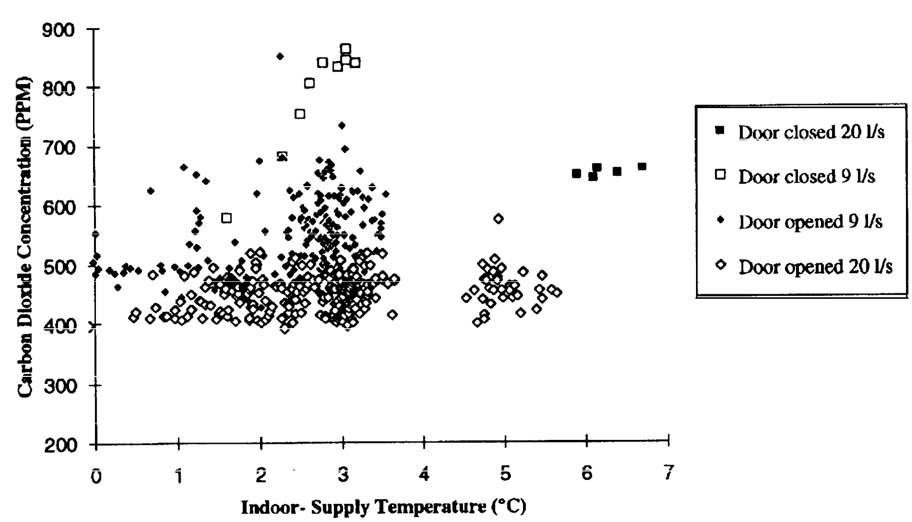

Figure 4. Carbon Dioxide Concentration Measured as 15-Minute Mean Values During Working Hours m the Kroken Building

Air Distribution

The air change efficiency was measured by dosing tracer gas (N_2O) in the room to a 100 ppm level and measuring the decay at the exhaust air outlet. This was performed with and without mixing fans. The air change efficiency was then calculated by comparing these two measurements. At complete mixing, the air change efficiency is 50%.

In two of the offices, the air change efficiency was improved when the ventilation air flow was reduced. The improvement can be a result of the fact that stack effect from people and equipment increases relative to ventilation air flows at the reduced air flows. The measured air change efficiencies are given in Table 4. For the third office, there was no change. It is interesting to note that the supply air temperature in this office was a couple of degrees lower than the room temperature at normal operation but basically isothermal at test operation. This shows the importance of adjusting the supply air temperature when air flows are changed.

The knowledge of convection currents is of great importance as they influence the indoor air quality in the room and the occupied zone. Smoke measurements revealed that the air change efficiency and the air distribution were not worse at reduced air flows. An increased air flow does not seem directly proportional to improved mixing or indoor air quality.

Carbon Dioxide Levels

The measurement results of carbon dioxide is given both as absolute real time concentrations and in relation to the room load, which was defined as the temperature difference between room and supply air, for the different operating cases.

The results show that the CO_2 concentrations never exceeded 1000 ppm regardless of ventilation air flow or if the office door was closed or not. When the door was closed and two people occupied the room, the concentrations increased to about 1200 ppm. During nights and weekends, the level was about 400 ppm which increased to about 600-700 ppm at the end of an office day. The difference between normal and test operation was between 50-100 ppm with open door and up to 250 ppm with closed door. The increase in CO_2 concentration owing to reduced air flow is less than expected from calculations which probably was a result of that the door was not closed for sufficiently long period of time for the concentration to reach equilibrium. The increased air change efficiency measured at reduced air flows could also have contributed.

The CO_2 concentration relative to the room load is exemplified for the Kroken office in Figure 4. The CO_2 concentration is compared to the room load quantified as the difference between indoor and supply air temperature.

Temperatures

The outdoor temperatures varied between -14 and +10°C during the test periods. The room temperatures for the three offices varied between 19 and 234°C during work hours. During nights and weekends the temperature dropped to between 17 and 19°C. The temperature gradient between 0.1 and 1.6 m height varied between 0.3 and 2.0°C. Comparing the room and supply air temperatures with outdoor temperatures, the results differ between the offices.

Table 4. Summary of Measurement Results and Conditions

		Yrket	Kroken	Romben
Supply air location		back wall	back wall	front wall
Air supply temperature	‘ c	overtemp.	sub temp.	isothermal
Building envelope condition		normal	good	bad
Design air flow	l/s”person	25	25	40
Measured air flow normal/test	l/s”person	27/1 1	20/9	40/19
Specific efficiency flow normal/test	$kW/m^3/s$	4.3/1.7	2.4/1.4	4.9/2.4
Air change efficiency normal/test	%	39/44	45/46	42/46
Noise level	dBA	38/32	41/33	52/38

In the Yrket building, the supply air temperature sometimes was colder and sometimes warmer than the room temperature. The supply air thus both heated and cooled the room. At reduced air flow, the room temperature dropped, primarily at temperatures above 0°C. At lower outdoor temperatures, the heating system seems to obtain more authority, which is why the difference was reduced. The complaints of too low room temperature and decreasing room temperature with outdoor temperature, can be reduced by proper commissioning of the heating system.

For the Kroken building, the reduction in room temperature with outside temperature also could be seen although the room temperatures were not perceived as too low. The supply air temperature was increased by 2-3°C at reduced air flow to about the same level as the room temperature which made the air supply almost isothermal. This means that the room temperature was increased somewhat when the air flow was reduced. In order to not supply too much heat through the supply air, the temperature should be lowered at reduced air flow. No draught problems have been noticed in any case because the throw length is below one meter. The low temperature gradient, 0.2-0.3°C, implies good mixing, which also was confirmed by the tracer gas tests.

In the Romben building complaints of varying indoor temperature existed, which also was confirmed by the temperature measurements. During nights and weekends the room temperature dropped to 16°C and increased during the working days to about 23°C. This implies great heat losses through the building envelope. The windows in this building are only of double glazing and larger than in new buildings. At the high air flow during normal operation with about 20°C temperature on the supply air, the room temperature increased relatively quickly after the fans started. When office equipment and people supplied heat, the supply air cools the room. At reduced air flow, the supply air temperature was increased a little and the cooling effect was decreased. Down to -13°C in outdoor temperature, which was the coldest day during the measurements, the complaints of low and varying room temperatures ceased to exist. The mixing effect was very good, the temperature gradient being below 0.2°C. The thermostatic valves should be replaced with working ones to further reduce the daily temperature variations. The results show that the connection between air flow and temperature difference between supply and room air has to be considered in order to make the ventilation system work at different air flows. Measurements and follow up studies have to be performed for every building where seasonal ventilation air flows are to be applied. At the same time, the results indicate that it is easier to obtain more advantageous room temperatures at lower air flows during the heating season. During the summer, the conditions are the opposite.

Relative Humidity

That too dry air in office buildings is common during the winter season is confirmed by this investigation. The measured relative humidity levels were low, approaching 10% for the driest cases. The measured range was 12-35% RH, which is low compared to desired relative humidity levels (Arundel et al. 1986).

A small increase in relative humidity at reduced air flows was measured. In principle, the moisture content of the outdoor air was the dominating factor. Very little moisture was produced in the offices which thus requires a further decrease in air flows to significantly increase the relative humidity.

Volatile Organic Compounds

The results from measurements of TVOCs in the Yrket building showed low concentrations, below 70 g/m^3 (Decan equivalents) without external influence from sources such as traffic. The influence from the exterior environment is probably larger than emissions from building and furniture materials if the building the ventilation system have been operating for a long period of time.

Summary and Discussion

Some of the results and important factors are summarized in Table 4. In general, the measured difference between normal and test operation using technical measurements was small, in many cases smaller than the scatter in the measurements, in spite of the great care performed in taking the measurements.

The main differences were found in CO_2 concentrations, noise reduction and relative humidity.

Conclusions

The results showed good possibilities to reduce ventilation air flows during a major part of the year. Reduced use of electricity and heating energy can be obtained without negative consequences on the indoor climate as measured by the environmental factors. This was supported by the results of the questionnaires. The indoor relative humidity level is increased in winter, which reduces the amount of complaints on too dry air. Problems with noise, draught, and dust can also be reduced. CO_2 concentrations increase, but not above 1000 ppm in this study.

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