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Indoor Climate and Indoor Air Quality in Residential Buildings

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Abstract

In buildings which were built within the last 15 to 20 years, or which have been retrofitted, and which do not feature a mechanical ventilation system, air changes between 0.01 h^{-1} and 0.5 h^{-1} were measured while windows were closed. In the bedrooms of such buildings, when doors and windows were closed, CO_2 concentrations of up to 4300 ppm were measured whereby the 1500 ppm limit was often exceeded. Simulation calculations and diverse measurements using different door positions with simultaneously closed windows have shown that with the door open more than 10 cm, and a minimal air exchange in the whole of an apartment of 0.1 h^{-1}, a CO_2 concentration of 1500 ppm was not or was only insignificantly exceeded even after 10 hours. Investigations in a dwelling fitted with a mechanical ventilation system have shown that air quality and the indoor climate parameters were in an optimal range.

KEY WORDS:
Carbon dioxide, Ventilation, Ventilation requirements, Indoor air quality, Bedroom

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Introduction

Since the middle of the seventies, energy-related questions have taken an important place in renovations and new building construction. In the initial phase, a lot of effort was put into minimising transmission losses. By means of facade insulation, more appropriate building materials in general and better insulated windows in particular (double glazing), a significant energy-saving potential could be achieved. From this, energy losses through controllable and uncontrollable ventilation (convective) have increasingly become of primary importance. In particular the uncontrollable, and for energy-related reasons undesirable, infiltration of cold outdoor air through wall frame leakage and cracks is nowadays counteracted by careful sealing of the building structure of residential dwellings. This prevents undesirable air exchanges, caused mainly by wind- and temperature-induced pressure differences, between the interior and exterior of buildings.

These building practices may, under certain circumstances, cause indoor climate and indoor air quality problems. This is the case with well sealed buildings, particularly in residential dwellings that have not been fitted with a ventilating system.

In a first phase, towards the end of the seventies and at the beginning of the eighties, it was discovered that in dwellings with greatly reduced outdoor air intake, problems with humidity may arise (Korsgaard, 1983; Wegner, 1983; IEA, 1991/1).

As at that time – and even in part now – the behaviour of the occupants was seen to have caused such problems, a second phase (middle to the end of the eighties) produced diverse studies which investigated the ventilation behaviour of the occupants of apartments without mechanical ventilation (Brundrett, 1977; Dale and Smith, 1985; Lundquist, 1985; Lundquist and Revsbech, 1986; Dubrul, 1988).

The results of these studies show that the ventilation behaviour of the occupants is influenced to a large degree by spatial and climatic conditions as well as psychological, cultural and social factors. The level of outdoor air infiltration, the tightness of the building structure and the size of the apartment do not seem to have an influence on the ventilation behaviour of the occupants.

This leads to the conclusion that the inhabitant and his/her ventilation behaviour cannot be held responsible for the existing situation, but that the technical development and the environmental policy requirements have changed too rapidly. This has created a conflict between ventilation and energy-saving.

Van Dongen and Phaff (1989) have summarised these problems as follows: "... that the problems experienced with indoor climate parameters are not predominantly caused by lack of goal-oriented behaviour by the occupants, but by technological and architectural solutions which are insufficiently adapted to the behavioural patterns and wishes of the inhabitants." This makes it clear that a solution to the problem of overly well sealed building structures will not come about through behavioural change by the occupants, which would be very hard to achieve anyway, but that additional measures are necessary. The humidity problem is tackled today by technical solutions and simple behavioural rules which are easy to follow. However, even today, it is often not recognized that overly sealed building structures lead not only to a humidity problem but also to a problem of indoor air quality. This sets the objectives for a third phase (from the middle of the eighties to the near future).

Regarding sufficient air quality and a comfortable indoor climate, the situation in bedrooms deserves particular attention. In order to satisfy the life-essential need for rest, human beings spend up to a third of their time in this environment. Diverse studies have already been directed at the indoor climate and air quality of bedrooms (Dale and Smith, 1985; Lundquist, 1985; Lundquist and Revsbech, 1986; Ruotsalainen et al., 1989; Fehlmann et al., 1990). The air exchange rates measured in these studies cover a range between 0.01 and 12 h^{-1} and the highest CO_2 concentrations in bedrooms measured or calculated respectively were over 5000 ppm. These results clearly show that air quality problems may arise particularly in bedrooms. Within the above described set of problems the following questions were formulated:

- How does the ventilation behaviour of occupants influence indoor climate and air quality in well sealed dwellings without ventilating systems?
- How can a sufficient air quality and comfortable indoor climate be ensured and what are the minimal requirements for air exchange?
- Are modern ventilating systems suitable for residential dwellings?

Material and Methods

The investigations took place in residential buildings with and without mechanical ventilation.

Group A: Residential dwellings without mechanical ventilation

- Measurements in five apartments of two apartment buildings with energy-saving designs. These dwellings were built between 1986 and 1988. Each of the buildings has a central ventilation unit (WC, bathroom and kitchen) which is, however, turned off during the night. The measurements were taken in October 1989 (Fehlmann et al., 1990)
- Measurements in five apartments from five other apartment buildings. All these dwellings were built before the energy crisis of 1973 and have since undergone retrofitting. Table 1 provides an overview of the measured dwellings. The measurements were taken during the heating period 1990/91.

Group B: Residential dwelling with mechanical ventilation

Measurements in a seven-room single-family house (basement: office; ground floor and first floor: living area) built in 1988/89. The facade of this house is highly sealed and highly insulated (HIT-Technology, Braun, 1989). To ensure sufficient air exchange, and to save energy, a mechanical ventilating system with two heat recovery units was in-

Table 1 Overview of the investigated dwellings of Group A (second group)

Apartment	Year of construction	Renovation	Ventilation unit	Number of occupants
A	1926	1986	none	1 or 2
B	1926	1986	none	1
C	1928	1985	none	2
D	1940	1978	none	2
E	1970	1988	exhaust air*	2

*) exhaust air in WC/shower, not in operation at night

stalled. The outdoor air is taken in via the drain pipe. The whole building is heated by a wood stove which is located in the entrance hall. The supply air is injected on the first floor into the two children's and the parents' bedroom. The air inlets are just over the floor. The air effluxes through slots above the doors and is subsequently extracted from the two bathrooms on the first floor, the WC/shower on the ground floor and the free-standing kitchen on the same level (kitchen/dining/living/wood stove). The ventilation flow in the bedrooms corresponds to that of a displacement ventilation system ("Quellüftung"). During operation of the wood stove, a large ceiling fan ensures a thorough mixing of the air in the house (distribution of heat). The ventilation unit is in use only during the heating period. The measurements were taken in February 1991.

Measuring Methods

Measurement of the air exchange (nL_{eff}). In the apartments of the first group of Group A, the air exchange was continually measured with the technique of constant tracer gas concentration (N_2O) for 12 hours during the night, along with parallel measurement of the relative humidity (Charlesworth, 1988). The measured air exchange at issue corresponded to the air exchange between the bedroom and the outside air on the one hand and with the rest of the apartment on the other. The CESAR (Compact Equipment for Survey of Air Renewal) system developed by LESO served as a fully automatic measuring and data collection unit (Niclass et al., 1990; Scartezzini et al., 1985). Every fifth minute measurements were taken of the same room by the electronic data collector, averaged and stored.

As a further measurement method in the dwellings of the second group of Group A and Group B, the air exchange was measured by the rate of decay method with N_2O as the tracer gas (Charlesworth, 1988). The measured air exchange applies for the entire building or the whole apartment as appropriate. For the determination of N_2O concentration in the measurements, an infra-red absorption recorder URAS-2 (Hartmann & Braun, Frankfurt) in combination with a 6-Channel Gas Switch was used.

Measurement of the carbon dioxide concentration (CO_2). In all of the dwellings the CO_2 concentration was measured continually in the bedroom and also in part in the living rooms, and then saved as a 5-minute average. As a measuring instrument a 2-Channel BINOS 100 NDIR-Gas analyser (Rosemount Baar) was used along with the silently measuring CO_2 measuring unit EGQ 10 (Sauter AG, Basel) and AROX 425A (Aritron AG, Ebmatingen). The CO_2 measurements were, as far as possible, taken in the middle of the rooms between 1 and 2 meters high at some distance from the head of the bed. In one bedroom from Group B the CO_2 concentration was additionally measured at heights of 0.5 m and 2 m. The measurements in the living rooms were similarly, as far as possible, taken in the middle of the room at a height between 1 and 1.5 m. Calculations were made solely on that time during which the bedroom was occupied (occupation time).

Measurement of the air temperature (T). The air temperatures were similarly measured continually and saved as five minute averages. The measurements were obtained using Pt-100 resistance measuring elements protected against heat radiation. In the measurements in the dwellings of the first group of Group A the air temperature was measured in a corner of the room under the ceiling. In all of the other dwellings the temperature was measured as far as possible in the middle of the room at elevations of 0.1 m, 1.1 m and 2.0 m. The exterior temperature was either measured or obtained from the nearest measurement station of the Swiss Meteorological Institute.

Measurement of the relative humidity (U). For the measurements in the dwellings of the first group of Group A the absolute humidity was measured with a BINOS 100 NDIR unit and converted mathematically into the relative humidity. For the measurements in the second group of Group A and Group B the relative humidity was established by the capacitance principle.

Recording of window and door positions during measurements. The door and window positions were recorded by means of a questionnaire.

Duration and number of measurements. In each of the five apartments of the first group of Group A the measurements were taken during two to three nights and days, in two rooms (parents' and children's bedrooms). In total 17 measurements were taken. The measurements in the second group of Group A were taken in each instance over four to five nights. For the evaluation 21 measurements were available. The measurements in Group B were taken over four consecutive nights.

Table 2 Measured air exchange rates and air supplies in the bedrooms of the apartments of the first group of Group A (outdoor air plus air from the apartment itself) by different user behaviour over twelve night hours. »open« means that the window or door was open by more than 10 cm.

Window	Door	Number of measures	Air exchange rate h^{-1}	Mean ± Std.-dev. h^{-1}	Air supply $m^3h^{-1}Pers^{-1}$	Mean ± Std.-dev. $m^3h^{-1}Pers^{-1}$
closed	closed	9	0.01-0.31	0.12 ± 0.1	0.16-9.3	3.1 ± 2.6
closed	open	1	0.5	-	10.5	-
open	closed	4	3.2-12.3	9.4 ± 3.6	100-320	193 ± 79

Additional investigations. By means of the dilution equation of McIntyre (1980) diverse simulation calculations relating to user behaviour were undertaken.

Results and Discussion

Group A (apartments without mechanical ventilation)

Air Exchange

Table 2 shows a compilation of the measured air exchange and air intake during the night in the bedrooms of the first group of Group A with different door and window positions.

With closed bedroom doors and windows the ventilation rates were, as expected, the lowest, and in six cases ventilation rates of below 0.1 h^{-1} were measured. From an hygienic point of view these rates are clearly too low.

With open bedroom doors and closed windows a sufficient ventilation rate of 0.5 h^{-1}, corresponding to 10.5 $m^3h^{-1}Pers^{-1}$, was measured.

With closed bedroom doors and open windows the measured ventilation rates were by far the highest. From an energy-preserving point of view, however, the air exchange rates must be considered to be excessive.

Table 3 Table 3: Air exchange rate and outdoor air supply in the individual dwellings of the second group of Group A. In dwelling E the ventilation unit of the WC/shower was in operation during the measurements. At night the unit was switched off automatically.

Apartment	Volume m^3	Air exchange rate h^{-1}	Outdoor air supply $m^3h^{-1}Pers^{-1}$	Outdoor climate Temp. °C	Outdoor climate Wind vel. ms^{-1}
A	32.0	0.236	3.8	0.6	3.1
B	27.0	0.105	2.8	7.2	5.7
C	154.6	0.126	9.8	6.8	4.6
D	186.6	0.094	8.8	-	-
E	239.1	0.177	21.2	0.2	1.9

*) exhaust air in WC/shower, not in operation at night

The resulting air exchange measurements correspond very well with the rates measured over a longer period in the same apartments during the heating period of 1988/89 (Gay et al., 1989; Niclass et al., 1990). However, those air exchange rates measure slightly higher due to the generally lower outside temperatures.

Table 3 lists the air exchange rates measured in the dwellings of the second group of Group A.

Apart from dwelling E, where the air extraction unit was in operation and the windows had not been replaced during retrofitting, the measured intake of outdoor air was generally too low, particularly in the case of dwellings A and B. In order to ensure sufficient air quality, an outdoor air intake of 12 to 15 $m^3h^{-1}Pers^{-1}$ would be necessary.

The measured air intake was generally too low in new or residential dwellings which had undergone retrofitting.

Carbon Dioxide Concentrations in Bedrooms

Table 4 shows the measured CO_2 concentrations of occupied bedrooms at night.

The highest CO_2 concentrations at night were measured when windows were closed and doors closed or only marginally open. If the bedroom door was opened by 10 cm or more while the windows were closed, the increase in CO_2 concentration was considerably lower than with closed or only marginally open doors. The lowest CO_2 concentrations were measured when the windows were completely opened.

A good overview of the effects which different ventilation behaviour has on air quality in bedrooms can be achieved by dividing the increase in CO_2 concentration during occupancy time (in minutes) by the number of people sleeping in the room. The result corresponds to an increase of CO_2 concentration per unit of time (here ppm per minute and person per hour).

Figure 1 shows a compilation of the measured average increase of CO_2 concentration in ppm per

Table 4. Table 4: Measured CO_2 concentration (median, maximum, increase during occupancy and increase per unit of time) at different occupancy rates and different occupant behaviour during the night in the bedrooms of Group A. closed = door closed; split = door marginally open (resting on door jamb); 10 cm = door 10 cm open; half = door half open; open = door fully open.

Window	Door	Number of measures	Number of occupants	CO_2 Median ppm	CO_2 Maximum ppm	CO_2 Increase ppm	CO_2 Increase (unit of time) ppm $min^{-1}Pers^{-1}$
closed	closed	10	2	999-2973	1182-4286	789-3364	0.74-3.92
closed	closed	10	1	740-1889	828-2453	196-2152	0.25-3.90
closed	split	1	2	2216	2739	2222	2.08
closed	10 cm	4	2	1382-1703	1578-1886	681-1413	0.63-1.63
closed	10 cm	1	1	942	1087	546	1.09
closed	half	1	2	1469	1701	1118	1.01
closed	open	3	2	986-1731	1318-1807	413-987	0.37-1.08
closed	open	1	1	720	881	573	1.17
split	closed	1	2	760	1210	835	0.73
split	closed	1	1	820	909	543	0.8
open	closed	2	2	519	615-718	219-331	0.23-0.35
open	closed	3	1	419-542	515-644	128-272	0.24-0.47

minute and person with different user behaviour. It can clearly be seen that with closed windows and a door gap of 10 cm and more, the increase of CO_2 concentration per unit of time is maximally only half as large as is the case with closed or only marginally open doors. It is also obvious that a completely open door in combination with a closed window produces the same effect as a closed door in combination with a marginally open window (< 10 cm), whereby closed windows do not result in energy losses during the heating period.

In one dwelling the effect of different door positions with windows closed on the CO_2 concentration in the bedroom and living room was measured over several nights. Figure 2 shows a comparison of the progression of CO_2 concentration in the bedroom and living room over two different nights in this dwelling with a completely open and a completely closed bedroom door. The curves in Figure 2 show the two extreme cases. With closed doors the CO_2 content in the bedroom rose to 2760 ppm during the course of the night, whereas the CO_2 concentration in the living room remained unchanged at 600 ppm until the occupants arose in the morning. However, if the bedroom door was completely open during the night the progression in time of the CO_2 concentration was almost identical in the bedroom and the living room. In the morning, before the windows were opened, the CO_2 level in both rooms was about 1800 ppm. In three other conditions, which were also measured (marginally open, open by 10 cm, half open), the increase of CO_2 concentration in the living room corresponded ever increasingly to the progression in the bedroom, whereby the CO_2 concentration in the bedroom rose in each instance by a smaller margin.

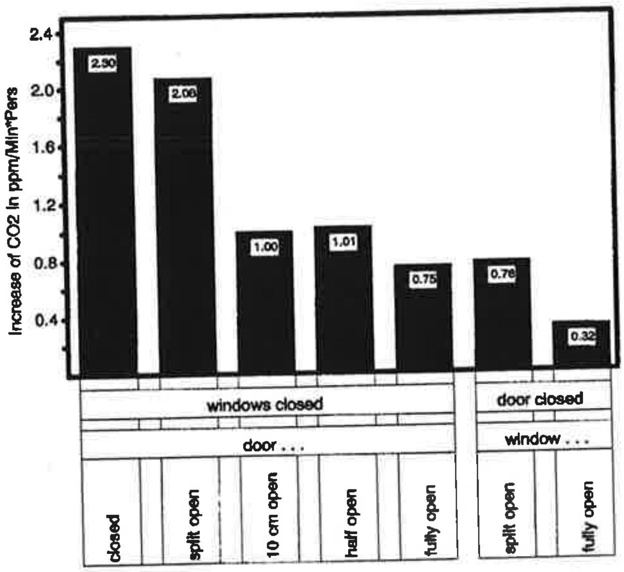

Fig. 1 Average increase of CO_2 concentration in ppm per minute per person for different bedroom door and window positions in the dwellings of Group A.

The results of the CO_2 measurements in the bedrooms of the dwellings of Group A lead to the following conclusions:

- The increase of CO_2 concentration is highest when the bedroom doors and windows are closed during the night;
- If the bedroom door is opened by at least 10 cm the increase per unit of time is only half as large;
- The smallest increase is achieved by opening the window.

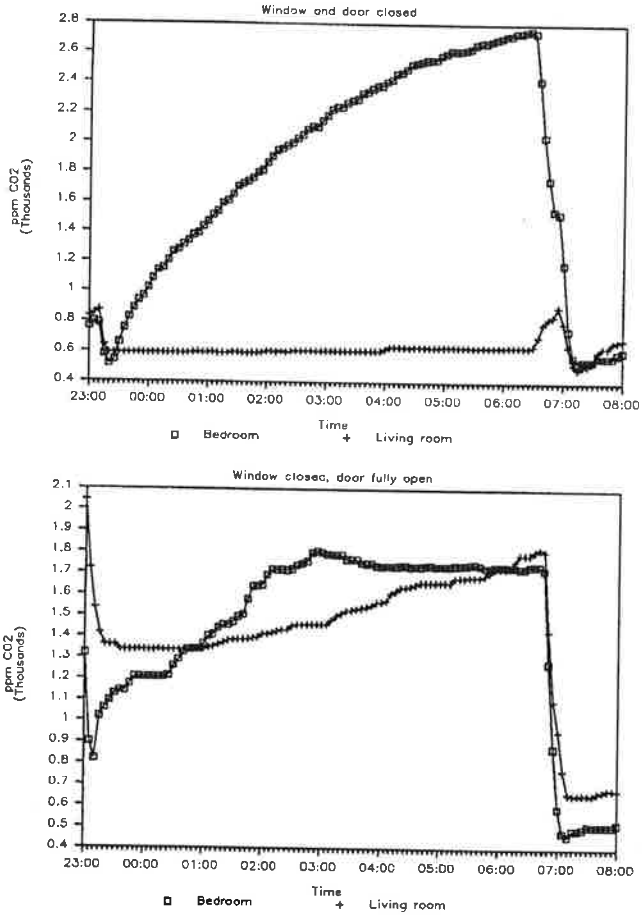

Fig. 2 Progression of the CO_2 concentration in the bedroom and the living room with open and completely closed doors over two different nights in the same dwelling

Simulation Calculations

To put the above findings onto a wider basis to make recommendations for optimal ventilation behaviour in bedrooms, dilution equations of McIntyre (1980) were used to make simulation calculations.

The following input data were used for the calculations. Occupancy of a room by two adults who produce together 24 litres of CO_2 per hour. The room volume of 33.7 m^3 was based on the average volume of the bedrooms of Group A. In order to simulate an open door, it was assumed that the additional volumes of the living room and corridor were available. This overall volume was fixed at 100 m^3. To simulate whether the apartment had been well ventilated or not prior to going to bed, CO_2 concentrations of 350 ppm or 1000 ppm were used at the beginning of the simulation. It was additionally assumed that the indoor air was homogeneously mixed. An observation time of 10 hours was chosen at different ventilation rates of 0.01h^{-1}, 0.1 h^{-1}, 0.5 h^{-1} and 1 h^{-1}.

Figure 3 shows the results of the simulation calculations. The simulation calculations lead to the following conclusions:

1. Bedroom door closed (V = 33.7 m^3)
   (a) Initial level of 350 ppm: At a ventilation rate of less than 0.5 h^{-1} the CO_2 concentrations quickly rises to more than 1500 ppm. At a ventilation rate of around 0.5 h^{-1} the CO_2 level will settle after an occupancy of 10 hours at 1700 ppm. At a ventilation rate of more than 0.5 h^{-1} the level remains below 1500 ppm.
   (b) Initial level of 1000 ppm: If the air exchange is less than 0.5 h^{-1}, CO_2 concentrations of 1500 ppm are also quickly exceeded. The CO_2 concentration remains about 600 ppm higher if the initial concentration is merely 350 ppm. At an air exchange of 0.5 h^{-1} or more the two curves, which start at 350 ppm and 1000 ppm respectively, approach each other relatively quickly. Therefore, the higher the air exchange, the less the influence of the initial concentration on the present concentration.

2. Bedroom door open (V = 100 m^3)
   (a) Initial level at 350 ppm: At a ventilation rate of about 0.1 h^{-1} the CO_2 concentration reaches a level of around 1500 ppm after 10 hours. This is due to the effect of the larger available air volume for the dilution of the exhaled CO_2. At an air exchange rate of around 0.5 h^{-1} the CO_2 concentration remains below 1000 ppm.
   (b) Initial level at 1000 ppm: At an air change rate of 0.1 h^{-1} a CO_2 level between 1500 and 2000 ppm is reached after 10 hours. At ventilation rates of 0.5 h^{-1} or more a dilution of the CO_2 takes place over the duration of the observation time. This is due to the fact that with a larger room volume and constant ventilation rate the outdoor air intake (in m^3h^{-1}) is correspondingly greater.

Air Temperature and Relative Air Humidity

The median measured room air temperature during the observation time was between 17.5 °C and 22.3 °C when the windows were closed and between 20.1 °C and 20.7 °C with open windows. The median outdoor air temperatures were between 1.0 and 9.8 °C.

The mean values of the relative humidity were between 40.0% and 64.7%. On average, the relative humidity with closed windows was around 10%

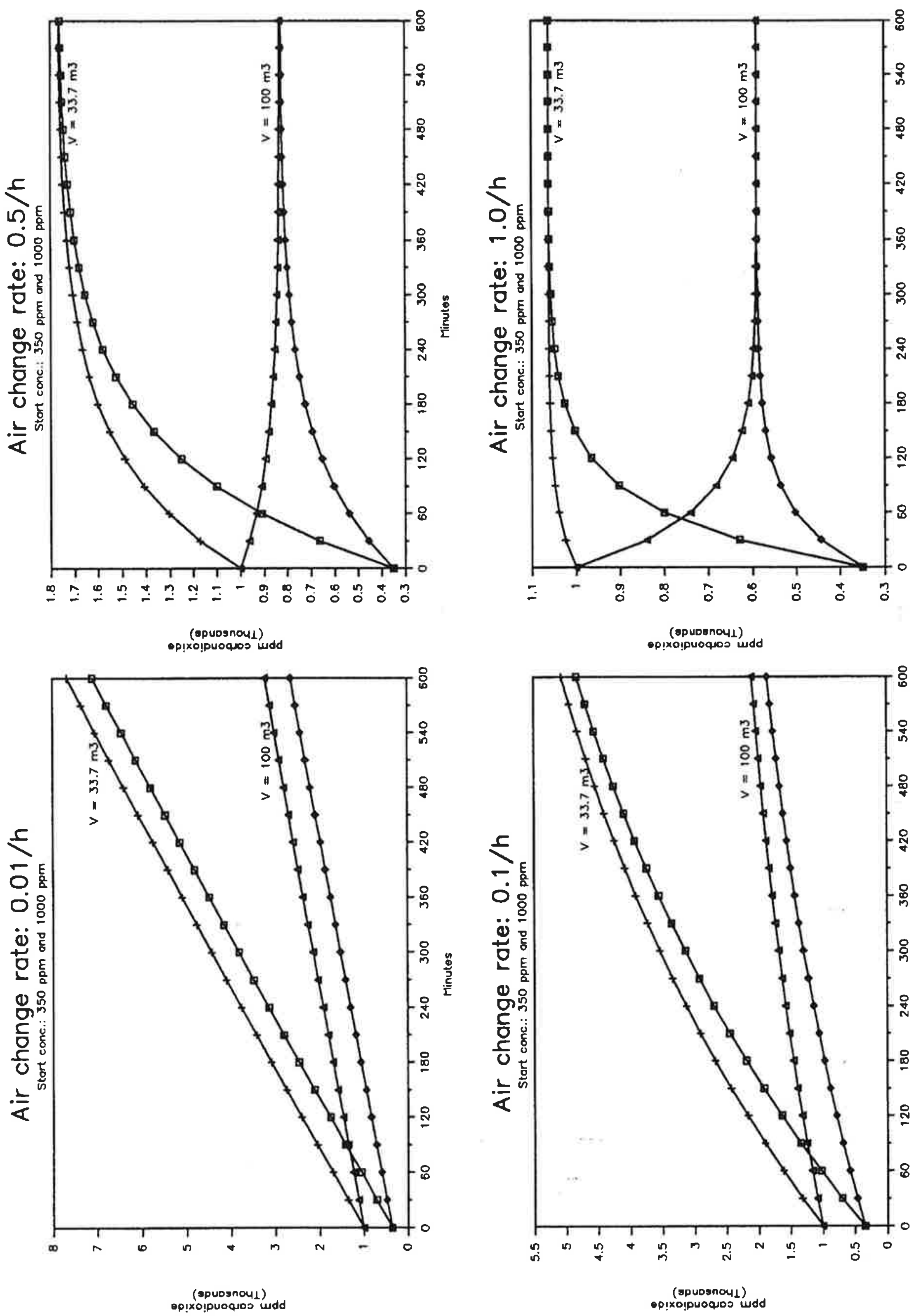

Fig. 3 Influence of the room volume, initial concentration and air exchange in relation to the CO_2 concentration over a given time period in a room occupied by two people.

Table 5 Table 5: CO_2 concentration in the living room and in the children's and parents' bedrooms during occupancy of the dwelling in Group B

	CO₂ concentration (ppm)					
	Living room	Children's bedroom	Parents' bedroom			
			1 person		2 persons	
			2 m	0.5 m	2 m	0.5 m
Median	626	610	949	820	1324	1131
Minimum	492	405	446	309	836	663
Maximum	1035	924	1347	1163	1378	1172

higher than with open windows. In both cases the relative humidity was over 60% with closed windows.

Group B (single-family house with mechanical ventilation)

Air Exchange

The air exchange (nL_{eff}) in the single-family house measured 0.3 h^{-1} while the ventilation unit was in operation. It was observed that for each room the quantity of 20 to 25 $m^3h^{-1}Per^{-1}$ outdoor air was supplied, corresponding to the rooms' purpose and normal occupancy.

Carbon Dioxide Concentration

Table 5 shows a compilation of the results of CO_2 measurements in the different rooms during the occupied time.

All measured CO_2 concentrations were generally fairly low and rose in the occupied zone only marginally above 1000 ppm. In the children's room the CO_2 level never exceeded 1000 ppm. Figure 4 shows the progression of the CO_2 concentration over one night with variable occupancy of the parents' bedroom.

On the basis of similar progressions of CO_2 concentrations in the air inlet and air outlet pipe it was observed that part of the exhaust air obviously got into the supply air. Figure 5 shows the progression in the supply and in the exhaust air. It can be seen that variations in the CO_2 concentration in the exhaust air resulted to a small degree in corresponding variations in the supply air. From the CO_2 concentration changes per recording interval (five minutes), which took place in the supply and exhaust air, it could be calculated that about 17% of the exhaust air in the heat exchanger got into the supply air. This should be avoided if possible in residential buildings such as this as it may lead to odour irritation from toilets, baths and kitchens. Heat exchangers for residential dwellings should be as "tight" as possible.

Room Air Temperature and Relative Air Humidity

Although the building was heated very economical-

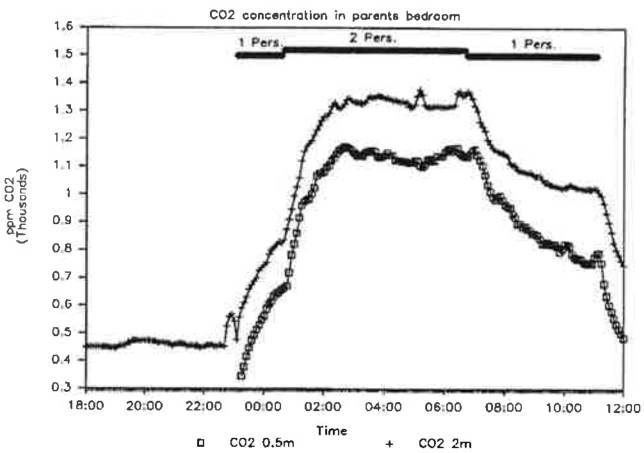

Fig. 4 Progression of CO_2 concentration at heights of 0.5 m and 2 m in the parent's bedroom of the dwelling with variable occupancy in Group B.

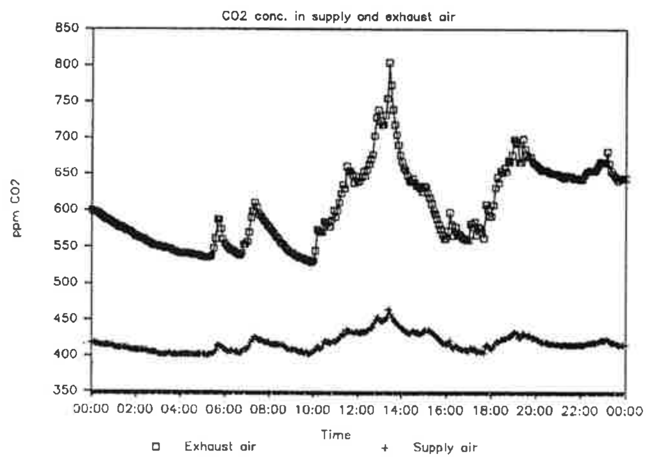

Fig. 5 Progression of CO_2 concentration in the supply and exhaust air over one day in the dwelling of group B.

ly by a wood stove, the minimum temperature never sank below 18 °C with windows closed. This can be directly attributed to the high thermal insulation of the building structure and the double heat recovery from the exhaust. In the parents' bedroom the average air temperatures were around 18.6 °C (at a height of 0.05 m) to 19.7 °C (at a height of 2 m). In the living room the average temperature was 20.0 °C.

The measurements of the relative air humidity yielded very constant values between 45% and 53% with an average value of 50%. Although the outside temperatures reached 0 °C during the measuring period, the relative air humidity never dropped below 45%. As already mentioned, the humidifying of the outdoor air is achieved by pumping air in through the drain pipe.

Conclusions and Recommendations

In buildings which were constructed within the last 15 to 20 years, or in buildings which have undergone retrofitting and which are not fitted with mechanical ventilation units, the resulting air quality will be insufficient within a very short period, if bedroom doors and windows are kept closed during the night (for whatever reasons).

On the basis of the knowledge gained through the investigations on the dwellings of Group A and Group B, it can be stated that the behaviour of the occupants considerably influences the indoor air climate in bedrooms of well insulated buildings. In regard to the ventilation of bedrooms in apartments without mechanical ventilation the following conclusions can be reached and the following simple-to-follow behavioural recommendations made. These will ensure the best possible air quality in the bedrooms of such dwellings and at the same time satisfy today's requirements for energy preservation.

- To ensure sufficient air quality in bedrooms an adequate supply of outdoor air is necessary.
- Outside the heating period this may be achieved by opening the bedroom windows during the night.
- With an air exchange of more than 0.5 h^{-1}, an occupancy of two persons, a bedroom volume of at least 30 m^3 and closed bedroom windows and doors, the CO_2 concentration will not exceed the 1500 ppm limit by a large margin.
- During the heating period it does not make a lot of energy sense to keep the bedroom windows open for longer periods of time. On the other hand, in airtight buildings, the air exchange rate is too low. Additionally, the occupants may be forced for other reasons (pollen allergies, external noise sources) to keep the windows shut during the night also outside of the heating period. In these cases, particularly in airtight buildings, it is recommended to keep the bedroom door open by at least 10 cm or more. If the whole apartment previously gets aired for 5 to 10 minutes by completely opening the windows, the CO_2 concentration will not, or only marginally, exceed the upper comfort limit even after 8 or 10 hours sleep. This is subject to the condition that the apartment has a minimal outdoor air infiltration rate of 0.1 h^{-1}.

The measurements performed in a single-family house fitted with a mechanical ventilation system have shown that the indoor climate and the air quality were in an optimal range and that mechanical ventilation is suitable for such applications. Several authors (van Dongen and van der Wal, 1990; Säteri et al., 1990; Ungerland, 1991) point out, however, that mechanical ventilation in dwellings may lead to similar problems as those experienced in office buildings with mechanical ventilation. With good planning of the building and the ventilation it is possible, however, to achieve a comfortable indoor climate and sufficient air quality.

Further efforts should be undertaken over the coming years in the area of apartment ventilation so as to satisfactorily solve the problems which have arisen due to the sealing of building structures. Additionally, the necessary input of outdoor air in relation to occupancy and use of rooms should be established.

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