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CIB.W-17 HEATING AND CLIMATISATION
1988 SYMPOSIUM

AIR EXCHANGE IN FLATS HEATED WITH WARM AIR

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1. INTRODUCTION

Råslätt is a dwelling area located near Jönköping in the mid-south of Sweden. This area has been the subject of measurements of the air exchange in flats heated in different ways. Originally compensation for heat losses due to transmission and air leakage was accomplished by electrical wall panels in the apartments. The supply air for ventilation was first heated in exhaust/supply air heat exchangers and then to room air temperature by electrical heaters mounted in the supply air ducts.

Recently a chiller/heatpump has been installed in the area. It is used to produce ice for the local skating court as well as to produce heat for the 30 apartment buildings. In order to make use of the heat, the electrical heaters in the supply air ducts will be exchanged to heating coils.

The heat output from the heatpump is enough also to reduce the use of the electrical wall panels. This can be accomplished by an increased heating of the supply air, which can cover the heat demand down to -8°C

The warm air will be supplied at inside walls, close to the ceiling. The air will leave the room through an opening just above the door. Normally doors will be open, allowing the air to leave the room at a high level, too.

It is known that severe stratification may occur when introducing warm air close to the ceiling, resulting in bad ventilation (1). Because of this it was decided to make measurements in a few apartments.

2. DESCRIPTION OF THE APARTMENTS

Air exchange were measured in two original and two redesigned apartments as shown in fig 1 and 2. The original apartments were supplied with air at 20-23°C. In the redesigned apartments, where also supplementary air supply devices were installed in the kitchens, air was supplied at 38-40°C.

The nominal supply/exhaust air flow rate is 150 m^3/h corresponding to 0,75 air changes per hour (ACH).

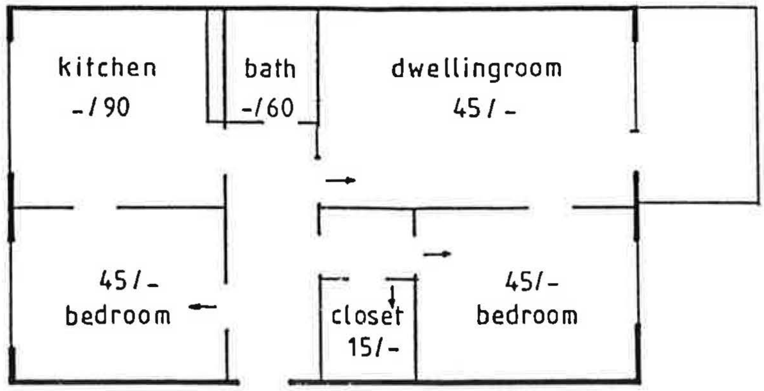

Fig 1. Plan of an original flat. (Area 80 m^2). Supply and exhaust air flow rates are given in m^3/h.

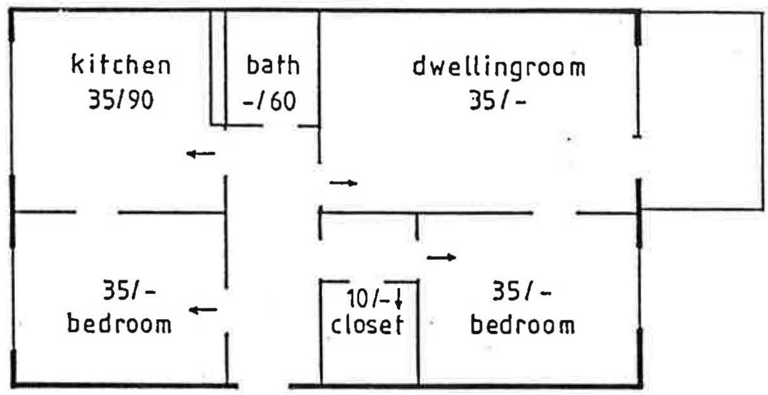

Fig 2. Plan of a redesigned flat. Supply and exhaust air flow rates are given in m^3/h.

The air was supplied from round openings 0,2 m below the ceiling at inside walls, see fig 1 and 2. Exhaust air was taken from kitchen and bathroom. Ventilation openings between the rooms were just above the doors.

The apartment buildings are equipped with 3 pane windows, and are relatively well insulated and sealed against air leakage. Electrical wall panels were located below the windows in each room.

3. ABOUT THE AIR EXCHANGE IN THE FLATS

Supply air should primarily be introduced near the people and exhaust air should be removed from near the contamination sources. In the flats studied this corresponds to supply air in bedrooms and dwelling rooms and exhaust air from kitchen and bathrooms. This is the way the original flats are ventilated. There is also supply air to the clothes closet.

In the rebuilt apartments the supply air is distributed also to the kitchen in order to meet the heating demand.

Normally, supply air flow rate is about 90% of exhaust air flow rate in order to decrease or eliminate over pressure in the building so that no condensation damages in the outer walls will occur. However, in this case nominal air flow rate for both supply and exhaust air is 150 m^3/h.

The primary objective of the air exchange study was the distribution of supply air, especially in the lower parts of the rooms. The most proper way of doing this is to measure the local mean age of the supply air at specific points in the rooms.This can be made in accordance with the Nord Test Standard (2).

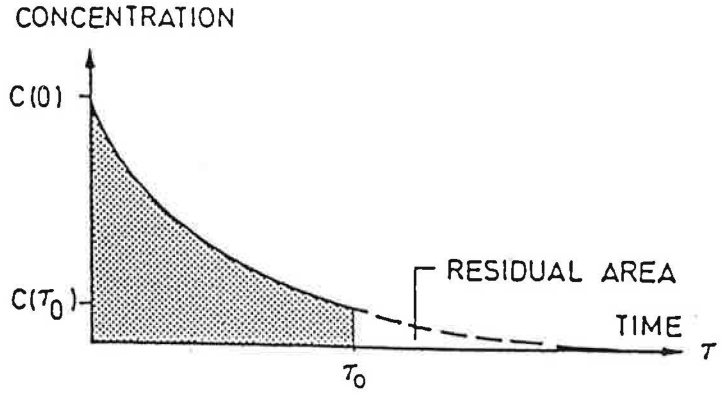

Fig 3. Illustration to the Nord-Test Method for determining local mean age of air.

It was decided however to make the measurements in flats in use and as used. It was then not possible to measure long enough for a steady concentration level to be reached. Fig 3 illustrates the problem. The figure is from the Nord Test Method and shows a case where a room initially had a uniform tracer gas concentration and then is ventilated with clean air. The local mean age of the air in the measuring point then is defined as

$$\tau_p = \frac{A}{C(0)}$$

where A is the total area below the curve and C(0) the initial concentration (in this case). We used the tracer gas in the supply air, instead. In the case at hand as in fig 3 there will be a residual area which is not measured. It is also difficult to extrapolate. A flat is from an air exchange point of view a system of interconnected zones. When the steady state in tracer gas concentration is approached, the rate of change is "controlled" by the zone with the slowest air exchange. This phase can be identified in a linear-log diagram by all concentration curves being parallell lines. Then an extrapolation of the residual area is possible to do. However, this phase can be reached very late.

In spite of these problems, from fig 3 and the definition of local mean age it is clear that the concentration curves themselves give valuable information about the level of air exchange. In this study measured data are reported in that way and no attempt to calculate the local mean age is made. The steady state balance level was taken as the concentration in supply air. This was justified by the fact that in all 4 measured flats the supply air flow rate was greater than the exhaust air flow rate, why leakage of outdoor air into the flat was not probable.

The intention of the study was to measure with the flat in normal use, with doors normally open and so on. In line with this the concentration measurements in the different rooms were taken with 1 or 2 persons in the room. It is clear that this increased the air mixing in the room compared with an empty room.

Outdoor temperature during the tests was a few degrees centigrade below zero. This meant that no wall panels where needed in the flats with warm supply air. No test were made with both wall panels in use and warm air supply.

4. EXPERIMENTAL METHOD

As tracer gas N_2O was used. It was introduced in the supply air at a level as steady as possible. The concentrations were close to 100 ppm.

Miran 1A, an infrared absorption instrument, was used for the concentration measurements and the signal was continously recorded on paper. The instruments were mounted on a trolley and moved between the rooms. Most measurements were taken at the trolley level which was 1,1 m above the floor, corresponding well with the breathing zone for a sitting person. Some measurements were also taken close to the ceiling and close to the floor by means of plastic tubes.

At each measuring point the recorded signal was observed and the measurement terminated when a constant rate of concentration change was indicated.

The supply and exhaust air flow rates were measured direct at the terminals. Also, the velocity of the supply air was measured and found to be in the range of 1-2 m/s.

5. RESULTS

The two original flats are called 1 and 2 and the two rebuilt flats 3 and 4. Supply air temperature in flats 1 and 2 varied between 20 and 23°C and in flat 3 and 4 between 38 and 39°C. Measured air flow rates are shown in table 1. Design air flow rates were 150/150 m^3/h.

	Room 1	Room 2	Dwelling room	Kitchen	Closet	Bathroom	Total
Flat 1	45/	32/	37/	/67	7/	/20	121/87
Flat 2	62/	47/	27/	/52	-	/55	136/107
Flat 3	27/	30/	27/	37/72	10/	/45	131/117
Flat 4	29/	37/	25/	39/74	13/	/17	143/91

Table 1. Measured supply and exhaust air flow rates (m^3/h)

The nominal volume of the flats are about 200 m^3 indicating values between 0,6 and 0,75 ACH (supply air). Furniture increases those values.

Fig 4 shows all measured values for flat 1. The reference curve corresponds to n=0.6 ACH (perfect mixing) and as can be seen all measured points indicate a greater air exchange. There is a considerable spread in these data. Although there are differences within individual rooms, as is shown in fig 5 for room 2, the spread is mostly due to the uneven distribution of supply air in the flat. This is illustrated in fig 6 with data for room 1 and the dwelling room. In this flat the doors to the dwelling room were kept closed. The logaritmic plot shows that this room behaves like a single zone, with good mixing. The fit for room 1 is not as good; if the last measuring point is neglected, there is a tendency toward becoming parallell with the dwelling room line. Also the "room 1 line" does not go through the point (0,1).

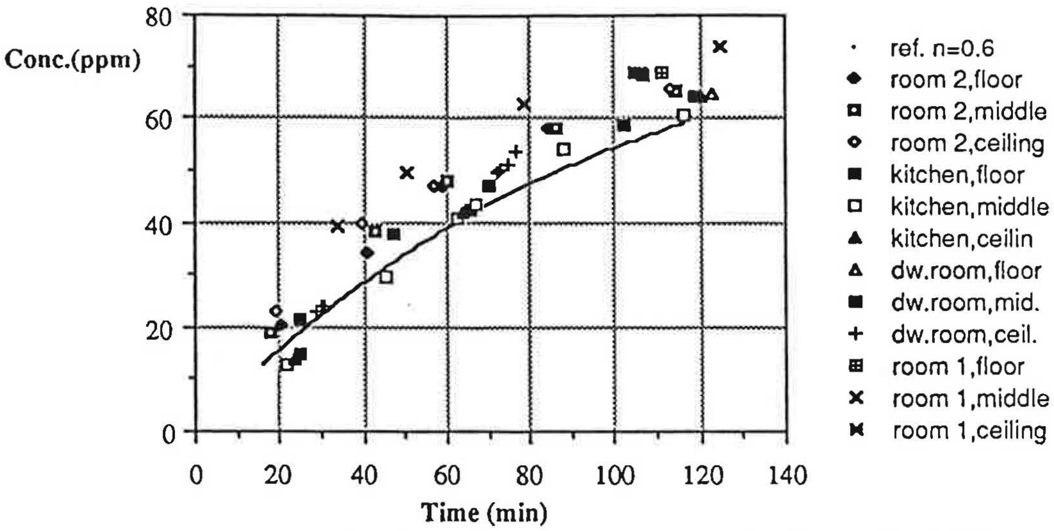

Fig 4. All measured values for flat 1. Tracer gas concentration in supply air 86 ppm. The reference curve corresponds to n= 0.6 ACH (perfect mixing)

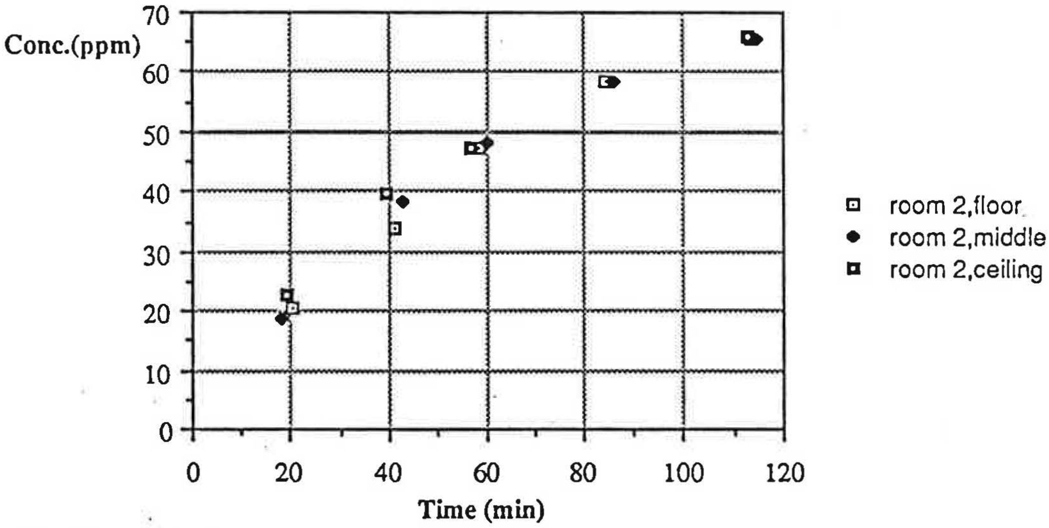

Fig 5. Concentration measurements in room 2, flat 1. C_S=86 ppm.

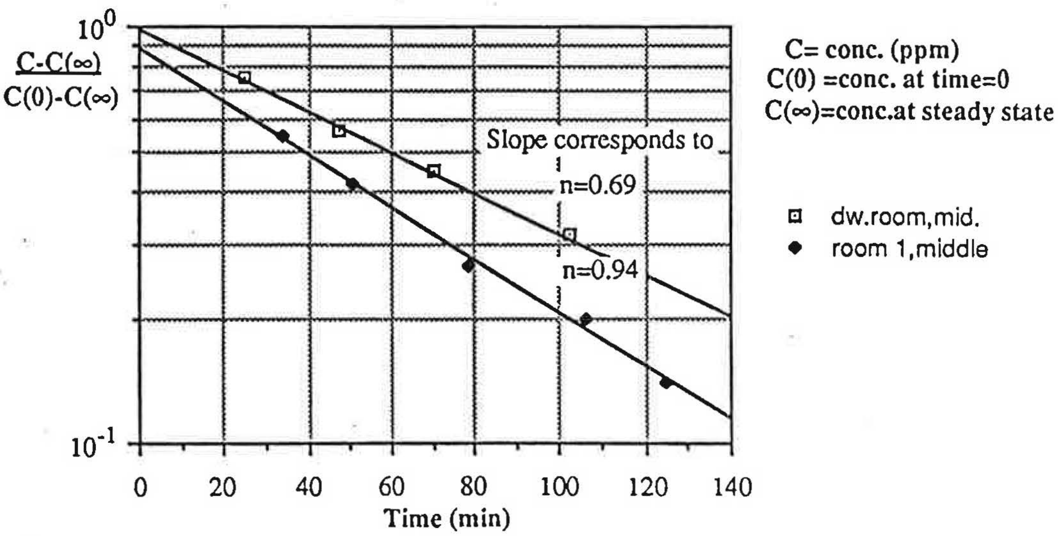

Fig 6. Concentration measurements for two rooms in flat 1 represented as relative decay curves. A straight line through (0,1) corresponds to perfect mixing.

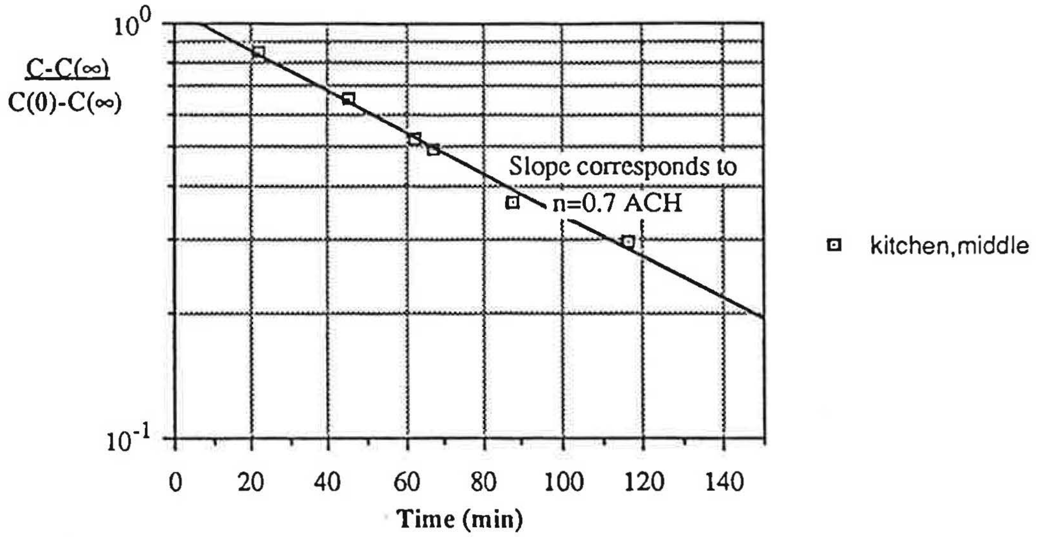

Fig 7. Concentration measurements in the indirectly ventilated kitchen. Observe the time lag due to transportation

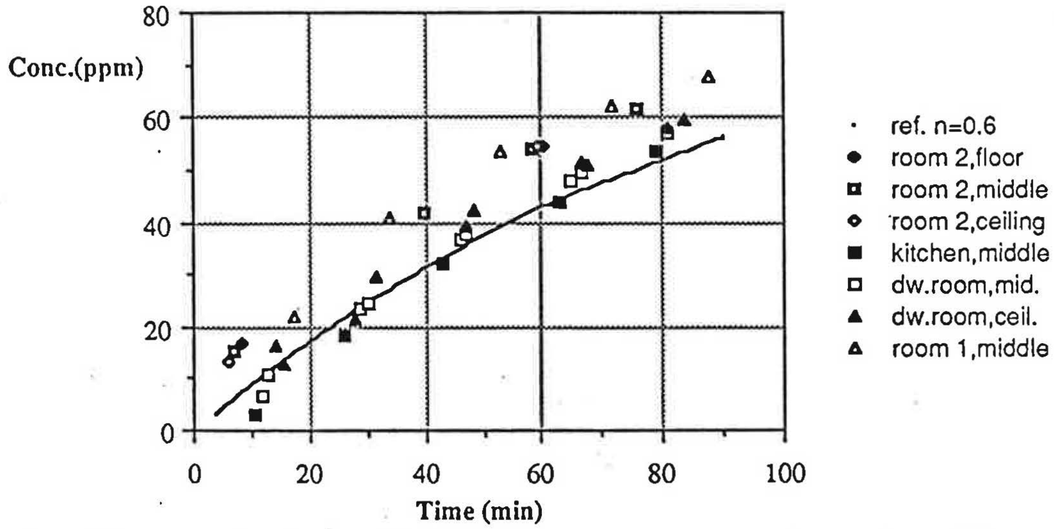

Fig 8. All measured values for flat 2. Tracer gas concentration in supply air 95 ppm. The reference curve corresponds to n= 0.6 ACH (perfect mixing).

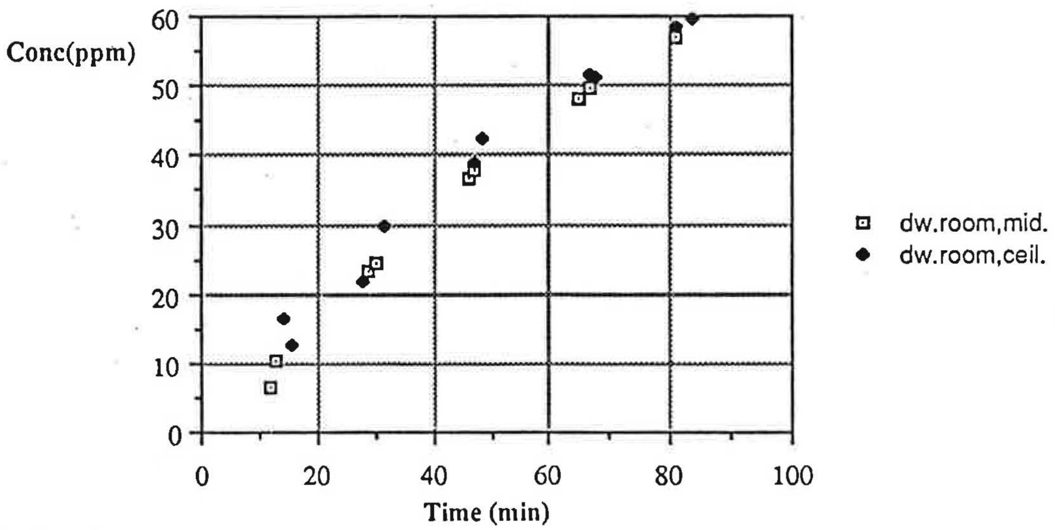

Fig 9. Concentration measurements in the dwelling room, flat 2. Measurements were taken at two different points at each level.

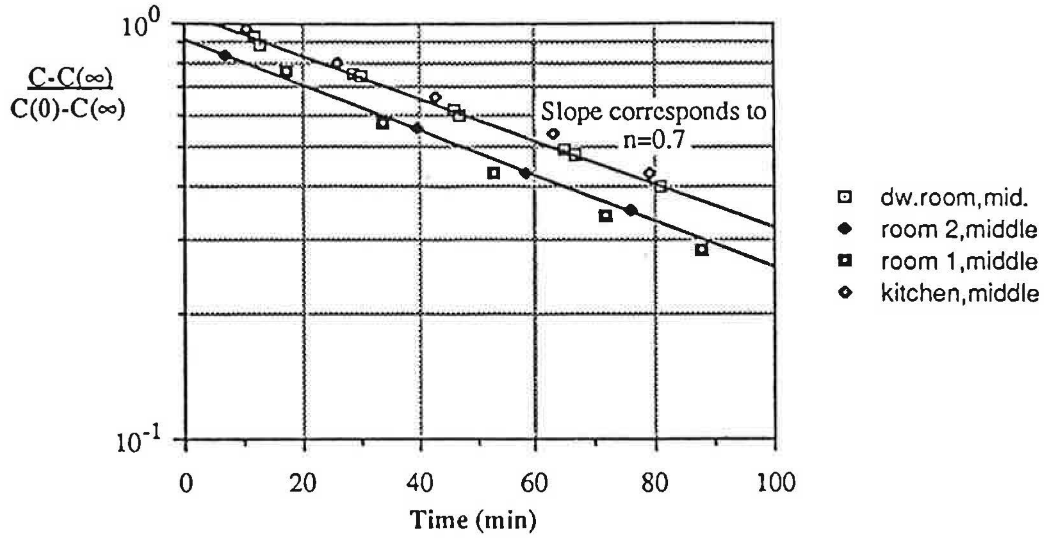

Fig 10. Relative concentration in all 4 rooms (middle) of flat 2. Note the tendency to the same slope for all 4 sets of measuring points at times greater than 40 minutes. This is due to the open connections in the flat. At times smaller than 40 minutes the 2 measuring points of room 1 and the point (0,1) fits a line with slope 1.

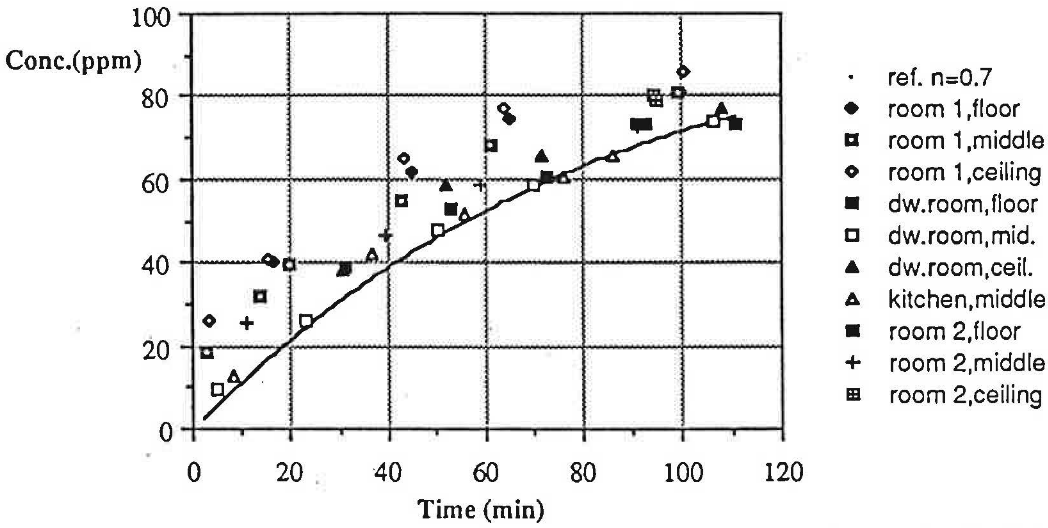

Fig 11. All measured values for flat 3. Concentration of tracer gas in supply air 104 ppm. The reference curve corresponds to n=0.7.

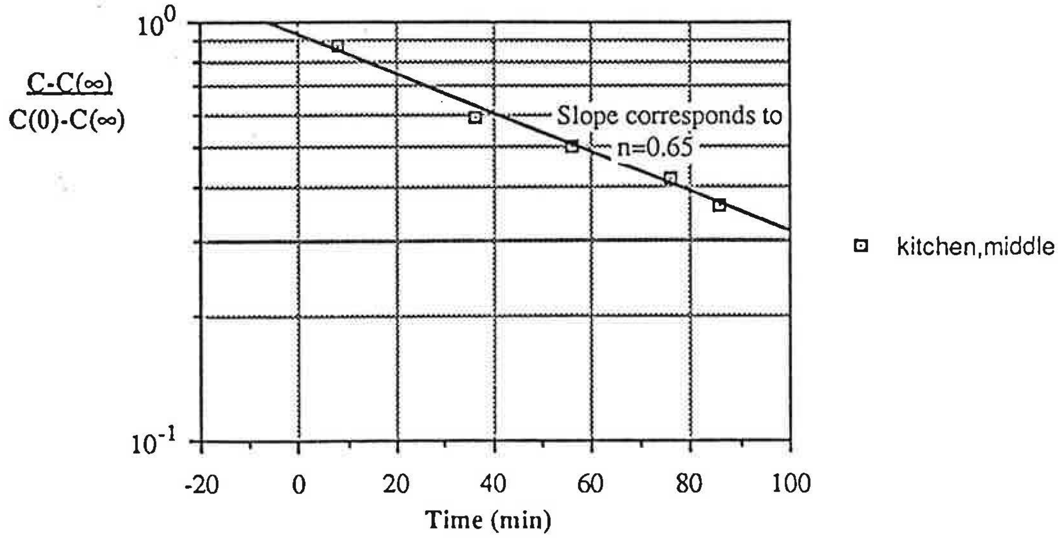

Fig 12. Relative concentration in the kitchen of flat 3. A positive time lag instead of a negative could be expected and data indicates that time 0 have been recorded wrongly with about 10 minutes. The slope corresponds to 0.65 ACH.

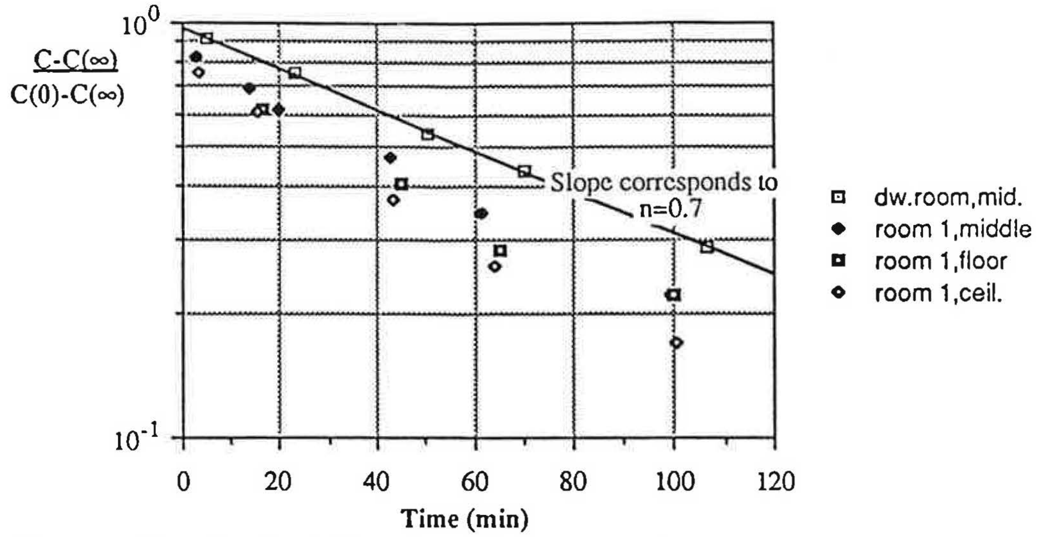

Fig 13. Data for flat 3. Note the differences within room 1.

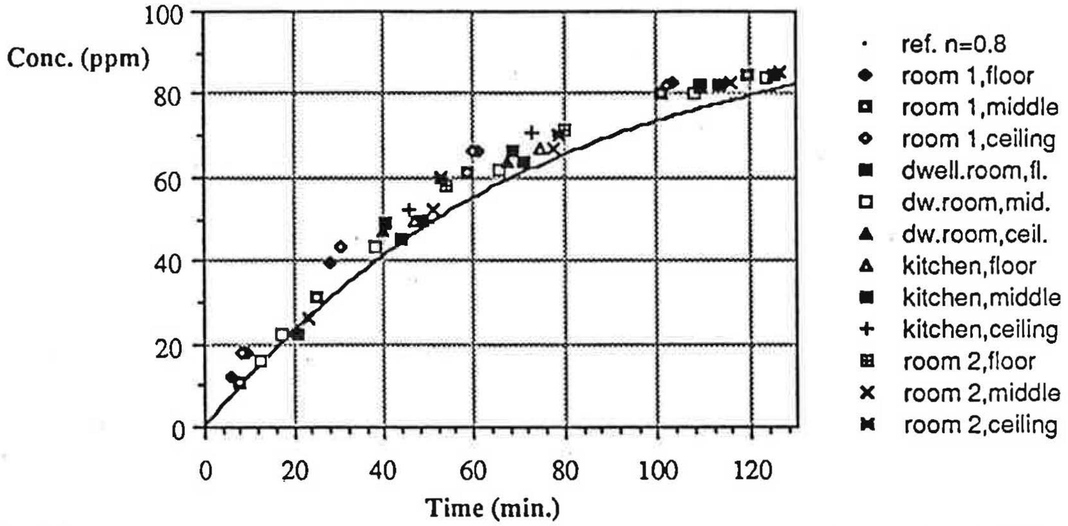

Fig 14. All measured data for flat 4. Concentration of tracer gas in supply air 100 ppm. The reference curve corresponds to n=0.8 ACH (perfect mixing).

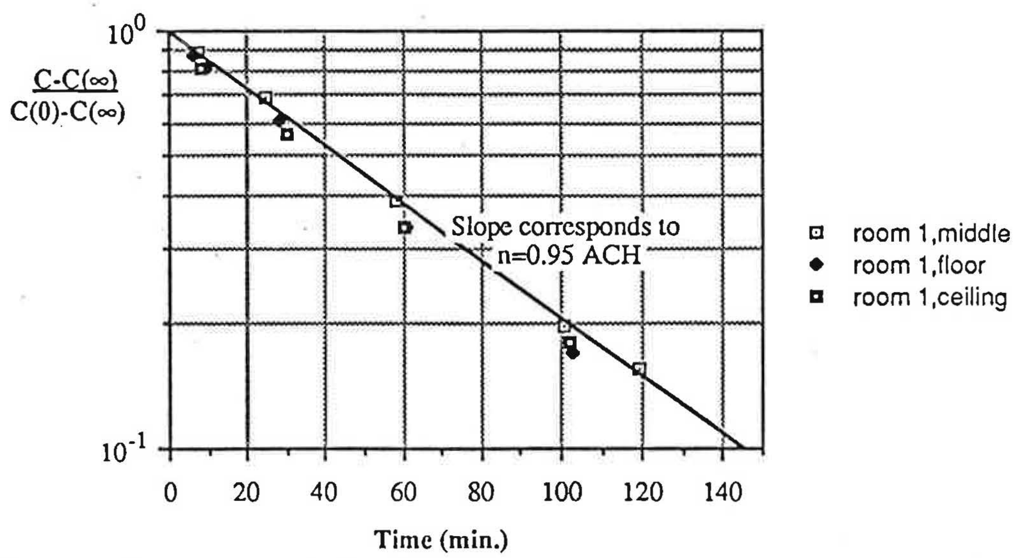

Fig 15. Data for room 1, flat 4.

Fig 7 shows a similar plot for the kitchen. Here the supply air first must be transported through the flat to the room, causing a time lag. Because most exhaust air is taken from the kitchen, the slope probably is representative for the total air exchange in the flat. Based on an empty flat this is 0,6, see table 1.

The time lag also explains the trend of the measured points for the kitchen, as seen in fig 4 and fig 7.

In flat 2 the distribution of supply air was more uneven than in flat 1 (see table 1). On the other hand, doors in this flat were open. The resulting spread in measured data for the flat was similar to that for flat 1 (see fig 8). Also, in this case the differences within a single room were rather small (see fig 9). Fig 10 shows relative concentration curves for the trolley level of all 4 rooms. Room 1 has the larger individual supply air rate and for this room the curvature of the set of measured points is evident. For times greater than 40 minutes a tendency is evident towards the same slope for all 4 sets of data .

Flats 1 and 2, discussed above, were ventilated with supply air of room temperature. Flats 3 and 4 were ventilated with supply air of 38-39°C.

Flat 3 was almost empty and not in use. Here all doors were kept closed as much as possible during the test. The spread is somewhat greater than in flats 1 and 2 (see fig 11). Also, the rapid initial increase of concentration indicates that perhaps a mistake in recording time 0 has been made. The total flow of supply air was somewhat smaller than in flat 2. As flat 3 was almost empty, a resulting value of 0,65 ACH for the whole flat could be expected to be measured in the kitchen where exhaust air is taken. Fig 12 shows this to be true.

The differences within single rooms were somewhat greater than for flats 1 and 2. Data for room 1 are reproduced in fig 13. The differences can be explained in terms of time lags. This is much smaller between ceiling and floor than between floor and middle of the room. In fig 13 data for the dwelling room (middle) are given also. This is partly to demonstrate the curvature of the data for room 1. Perhaps there is a tendency towards the slope of the dwelling room data for times greater than 60 minutes.

In flat 4 all doors but those to the bathroom and closet were open. Fig 14 shows that the spread in the data was very small. Fig 15 shows that also within a single room differences were not large but that there was the same tendency as in flat 3 for a time lag between data for ceiling/floor and room middle. This reflects the air circulation in the room.

Discussion

The results indicate that the air exchange in the two modified flats with supply air of 38-39°C is not severely disturbed by stratification tendencies. It is known that in an empty room severe stratification may occur. In this case one or two persons were in the room during the measurement which could be expected to cause mixing. In one of the flats, no. 4, one tenant was present during the measurements, mostly in the kitchen. The dominating mixing source probably was the convection air currents, expecially at the windows and front walls.

Another result was that in all 4 flats air flows were smaller than the nominal. There was also an unbalance between supply and exhaust air flow rates.

A redesign for warm air heating always is a conflict between air distribution for ventilation purposes and for heating purposes. In this case no room have sufficient supply air for two persons. The kitchen shall have no supply air but has,in order to meet the heating demand.

References: (1) Malmström, T-G and Ahlgren, A. Efficient ventilation in office rooms. Envir.Int. Vol 8 pp401-408, 1982.

(2) Nordtest Method NT VVS 019. Approved 1983-06. Nordtest SF.00340 Helsinki 34, Finland.