MEASUREMENTS OF AIR-EXCHANGE EFFICIENCY AND VENTILATION EFFECTIVENESS

Helenius, T., Seppänen, O., Majanen, A., Palonen, J.
Helsinki University of Technology
Espoo, Finland

ABSTRACT

Extensive measurements of ventilation effectiveness and air-exchange efficiency were made in a test room of 53 m^2. According to the tests the most reliable method of measuring ventilation effectiveness is to compare the concentrations at various locations during steady state conditions. Both mixing and displacement flow patterns were used with three nominal time constants (2h, 0.91h, 0.45h) and temperature differences -3 K to +3 K between supply and room air. The measured average ventilation effectiveness varied between 0.8 and 1.3 with mixing flow pattern and between 1.1 and 1.9 with displacement flow. The average air-exchange efficiency varied between 16 % and 56 % and between 46 % and 72 % respectively. The location of the human simulator affected the ventilation effectiveness much more than the nominal time constant and temperature difference. No reliable relation was found between the average ventilation effectiveness and the average air-exchange efficiency. A relation between average and local efficiencies was found.

INTRODUCTION

Normally the minimum fresh air flows in a building or a room are based on official rules. These rules do not take into consideration the performance of different kinds of ventilation systems and therefore the real air flows can vary greatly in the breathing zone. The purpose of this experimental study was to investigate in the laboratory the performance of various air distribution systems and the relation between indices used to describe the ventilation. The relationship between air-exchange efficiency and ventilation effectiveness was also studied with two air distribution systems.

EXPERIMENTAL SETUP

The measurements were made in a test room of 53 m^3 using tracer gas techniques and the decay method. Two tracer gases were used simultaneously. Carbondioxide (CO$_2$) was used to simulate contaminants in the constant source measurements and

Dichlorodifluoromethane (Freon 12) was used in the decay measurements. The concentrations were analysed with infrared analysers.

Ten measurement points were installed inside the room. Samples were also taken from the supply and exhaust ducts. The layout of the test room and the location of the measurement points is shown in fig. 1. There were no heat sources inside the test room apart from the lights (4·60 W) and the human simulator.

A human simulator was designed to simulate the contaminants released by a normal human. The idea was not to build a simulator looking like a man but to design a device which creates a similar kind of flow pattern as a human. The flow patterns created by a human /1/ and the simulator are shown in figs. 2a and 2b. A light bulb was placed inside the simulator to create a temperature difference between the air flow and the air inside the room.

Measurements were made with both mixing and displacement ventilation systems. A supply device situated on the floor was used to create a displacing flow pattern. The device was as wide as the room and the velocity of the air in the supply jet was very small (0.02-0.08 m/s). The exhaust duct was situated on the opposite side of the room, close to the ceiling. In the mixing flow pattern both supply and exhaust grills were situated side by side on the same wall, near the ceiling. The direction of the supply jet was horizontal. The distribution systems are shown in figs. 8a and 8b. Some earlier measurements were also made with other distribution systems using the measurer as a contaminant source (figs. 8c,d,e).

Three nominal time constants (2.0 h, 0.9 h, 0.45 h) were used in all measurements. The temperature differences between supply and room air varied between -3 K and +3 K. Two different locations of the human simulator were used (fig. 3). The simulator was also placed on the floor in some measurements.

CALCULATION METHODS

A decay method was used to determine the air-exchange efficiencies. The average air exchange efficiency was measured from the exhaust duct

$$\epsilon_a = \tau_n / 2\langle\tau\rangle \qquad (1)$$

where ϵ_a = average air exchange efficiency
τ_n = nominal time constant of air
$\langle\tau\rangle$= mean age of the air

The local ventilation index in breathing zone ϵ_o was calculated according to the average local mean age of the air in the zone τ_o.

$$\epsilon_o = \tau_n / \tau_o \qquad (2)$$

The nominal time constant τ_n used in the calculations was measured from the exhaust duct.

A constant source method was used to determine the ventilation effectiveness. The average ventilation effectiveness can be calculated from the step-up curve measured from the exhaust duct but a more reliable method is to compare the concentrations at various locations during steady state conditions.

$$\langle \epsilon \rangle = \frac{C_e(\infty)-C_s}{\langle C(\infty)\rangle - C_s} \qquad (3)$$

where $\langle \epsilon \rangle$ = average ventilation effectiveness
$C_e(\infty)$ = equilibrium concentration in exhaust duct
C_s = constant concentration in supply air
$\langle C(\infty)\rangle$ = average equilibrium concentration in the room

The local ventilation effectiveness in the breathing zone can be calculated accordingly

$$\epsilon_p = \frac{C_e(\infty)-C_s}{\langle C_p(\infty)\rangle - C_s} \qquad (4)$$

where ϵ_p = local ventilation effectiveness in breathing zone
$\langle C_p(\infty)\rangle$ = average equilibrium concentration in breathing zone

In order to be able to determine the average contaminant equilibrium concentration and the average local mean age of the air in the breathing zone a vertical profile of the local mean age of the air and the local ventilation effectiveness was measured. Figs. 4a and 4b show the profiles in four different cases with a displacement ventilation system. The breathing zone was 1,8m from floor to ceiling. In a two zone model it is possible to determine the volumetric parts of both zones from the whole volume according to the vertical profiles.

RESULTS

The measured average ventilation effectiveness varied between 0.8 and 1.3 with mixing flow pattern and between 1.1 and 1.9 with displacement flow. The temperature difference between the supply and room air did not greatly effect the values. With mixing flow the ventilation effectiveness decreased about 15 % when the temperature difference changed from 0 K to +3 K. With displacement flow the change was about +10 % when the temperature difference changed from 0 K to -3 K. The effect of the nominal time constant was not significant. The placing of the human simulator effected the ventilation effectiveness most. When the simulator was placed close to the exhaust duct the values were 20 to 40 % higher than in situations where the simulator was on the opposite side of the room. This was due to the short circuiting of contaminants from the simulator to the exhaust duct.

The measured air exchange efficiencies varied between 16 % and 56 % with mixing flow pattern and between 46 % and 72 % with displacement pattern. When the temperature difference varied between -3 K and +2 K the air exchange efficiency varied between 45 % and 60 %. When the temperature difference exceeded +2 K with mixing flow pattern the air exchange efficiency decreased significantly. A human simulator placed close to the exhaust duct decreases the air exchange efficiency, especially with the displacement ventilation pattern.

The relation between the average air exchange efficiency ϵ_a and the average ventilation effectiveness $\langle\epsilon\rangle$ was also studied (fig. 5), but no clear relation was found. It can be noted that when the human simulator was situated far from the exhaust duct, an approximate relation $\langle\epsilon\rangle=2\cdot\epsilon_a$ could be found.

A clear relation between the average air exchange efficiency of the whole room and the local ventilation index of the breathing zone was found (fig. 6). The relation is divided into two parts

$$\epsilon_o = 2.6\cdot\epsilon_a - 0.32 \quad \text{when } \epsilon_a \le 50\ \% \qquad (5)$$

and

$$\epsilon_o = 3.6\cdot\epsilon_a - 0.75 \quad \text{when } \epsilon_a > 50\ \% \qquad (6)$$

A similar kind of relation was found between the average and local values of ventilation effectiveness (fig. 7).

$$\epsilon_p = \langle\epsilon\rangle \quad \text{when } \langle\epsilon\rangle \le 1.0 \qquad (7)$$

and

$$\epsilon_p = 1.75\cdot\langle\epsilon\rangle - 0.77 \quad \text{when } \langle\epsilon\rangle > 1.0 \qquad (8)$$

DISCUSSION

The results of the measurements are shown in figures 8a-8e. The effect of the temperature difference on the results was not significant because of the small variation in the difference. These results support the measurements made by Sandberg /2/.

The human simulator used in these measurements best simulates contaminants released by humans. The simulation of smoking has not been studied thoroughly. The passive release of contaminants has not been studied but contaminants can be expected to equate with the air flow pattern.

The relations found between the average and local values of efficiencies in a single room are probably also found with other distribution systems. To clarify this, more measurements must be made with other systems.

CONCLUSION

There is no clear relation between average air exchange efficiency and average ventilation effectiveness. Therefore both efficiencies must be measured in order to determine the performance of an air distribution system.

The local ventilation index and ventilation effectiveness of the breathing zone can be determined from the calculated average values of the whole room. Therefore measurements need be made only from the exhaust duct, which simplifies the measuring procedure considerably.

REFERENCES

1. Mierzwinski.S., Air motion and temperature distribution above a human body in result of natural convection, KTH A-4 serie Nr 45, 1980.

2. Sandberg.M., Distribution of ventilation air and contaminants in ventilated rooms - theory and measurements. Tekniska Meddelanden no 279-280 Kungliska Tekniska Högskolan. Stockholm 1984.

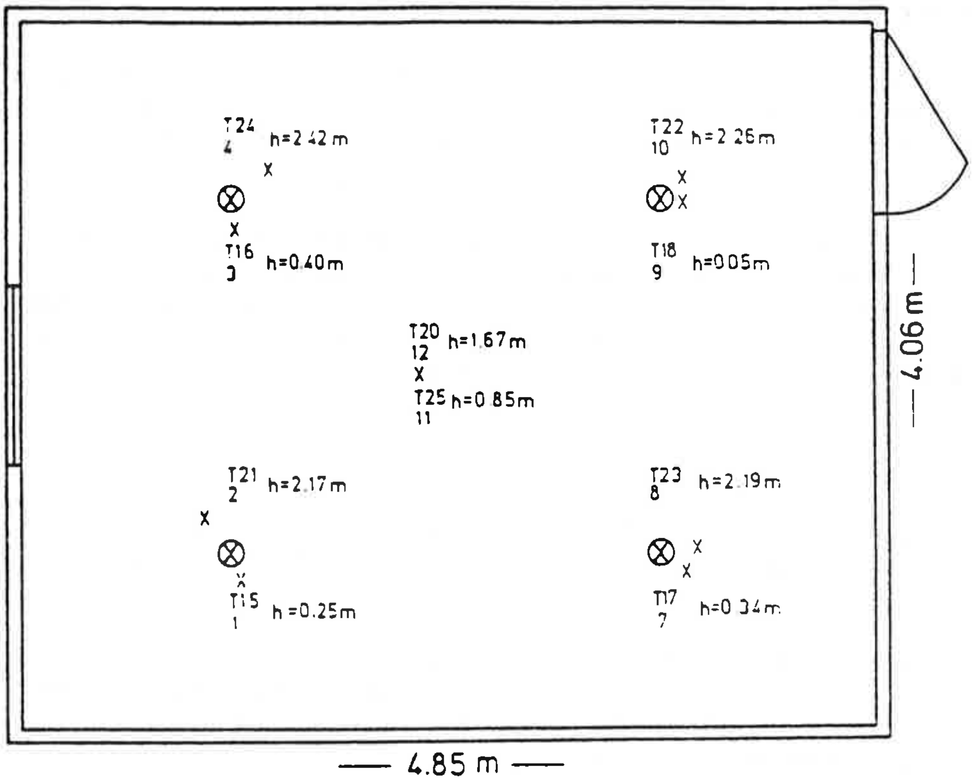


Figure 1. Placements of the measurement points in the test room.

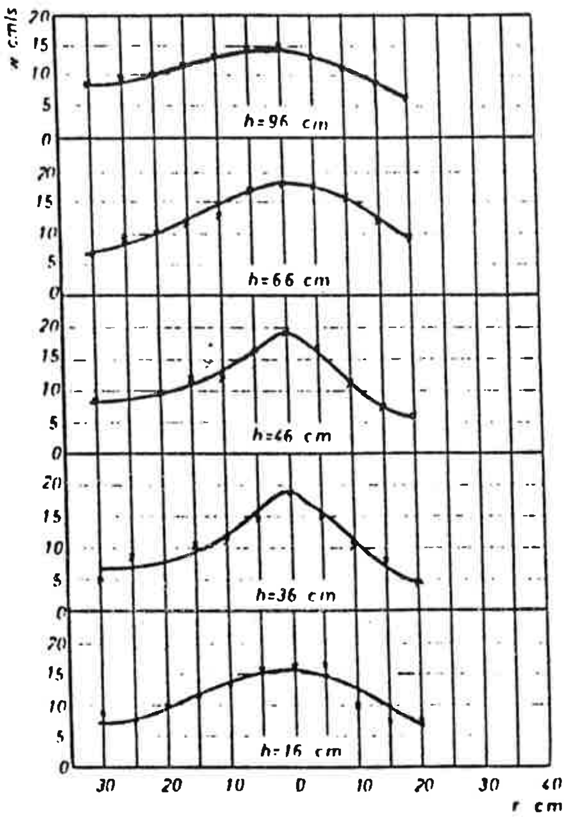


Figure 2a. The velosity profile above a human body /1/.

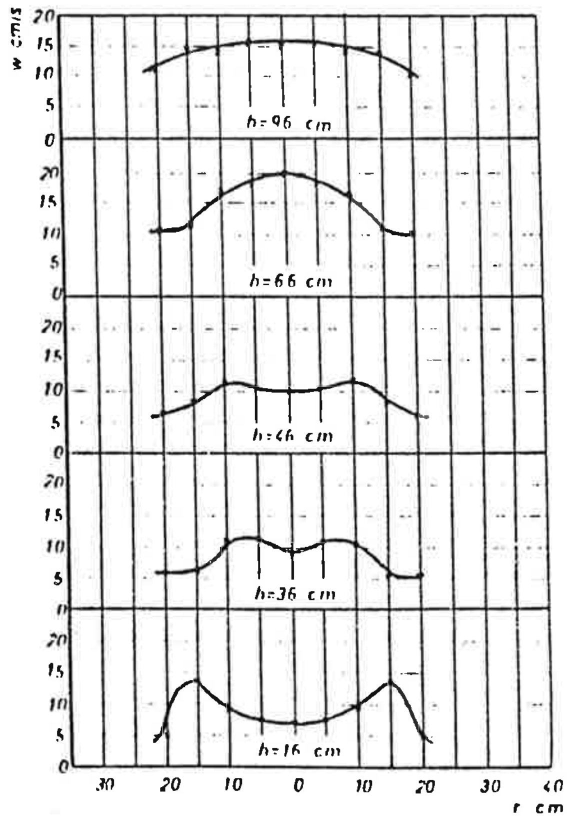


Figure 2b. The velosity profile above a "human" simulator.

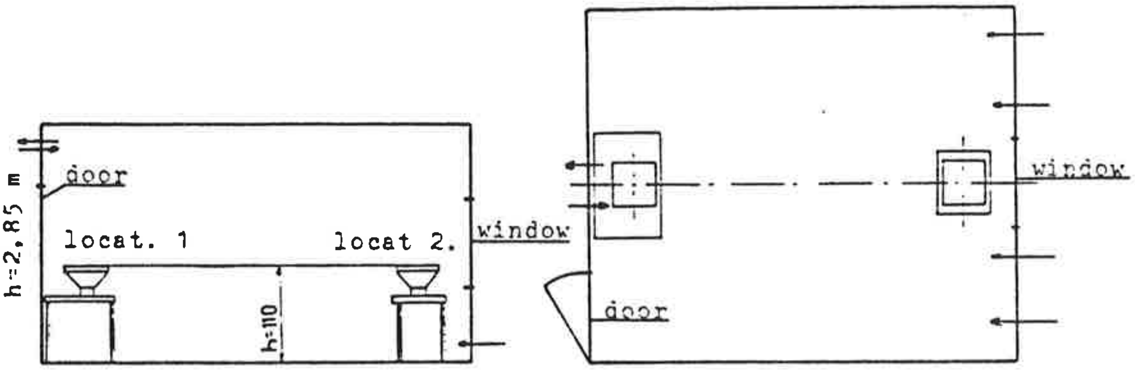


Figure 3. Different placements of the human simulator.

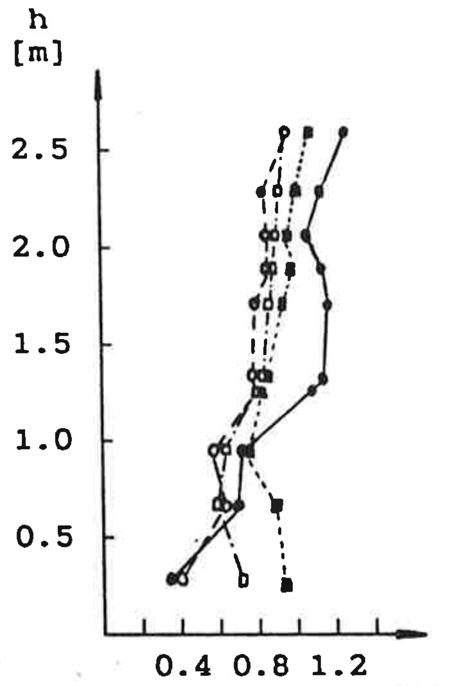


Figure 4a. Vertical profile of local mean age of air with displacement ventilation pattern.

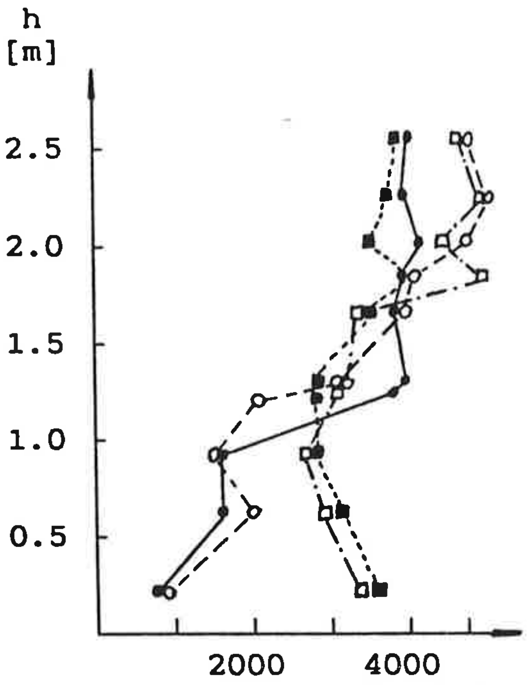


Figure 4b. Vertical profile of contaminant concentration with displacement ventilation pattern.

Where:

τ_n = 0.9 h , T = -2.4 K , simulator location 2
τ_n = 0.9 h , T = -3.0 K , simulator location 1
τ_n = 0.9 h , T = -0.3 K , simulator location 2
τ_n = 0.9 h , T = 0.1 K , simulator location 1

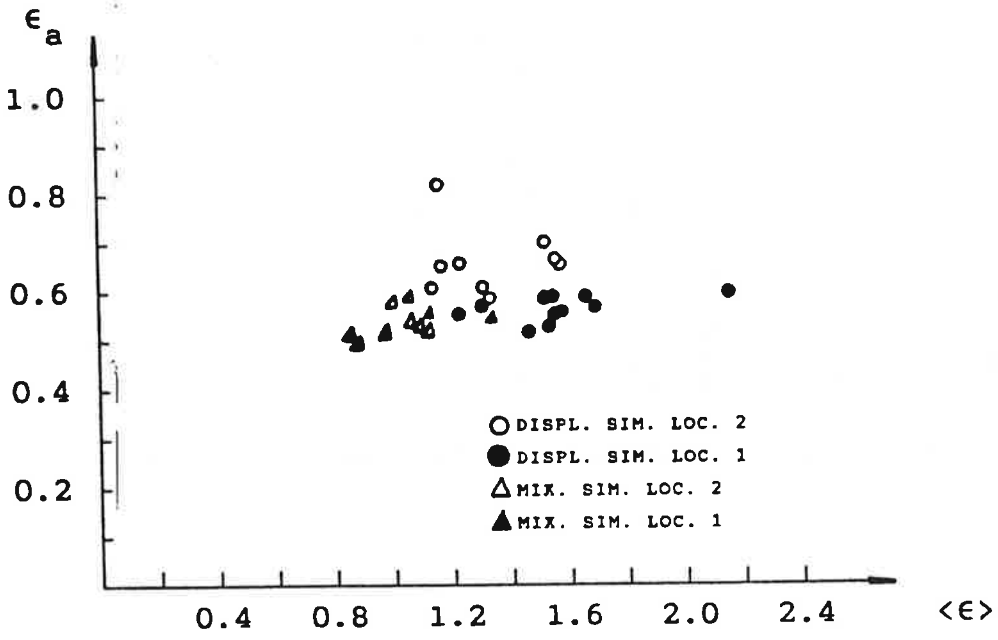


Figure 5. Relation betweeen ϵ_a and $\langle\epsilon\rangle$ in the measurements.

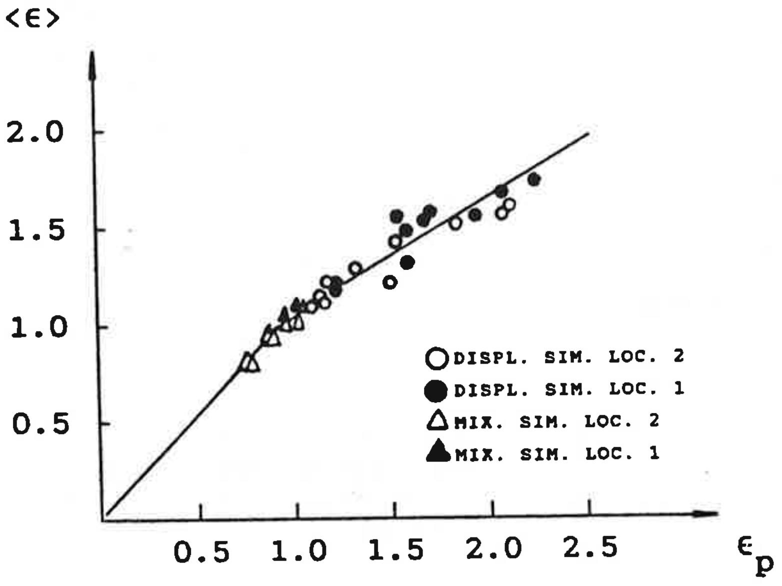


Figure 6. Relation between $\langle\epsilon\rangle$ and ϵ_p in the measurements.

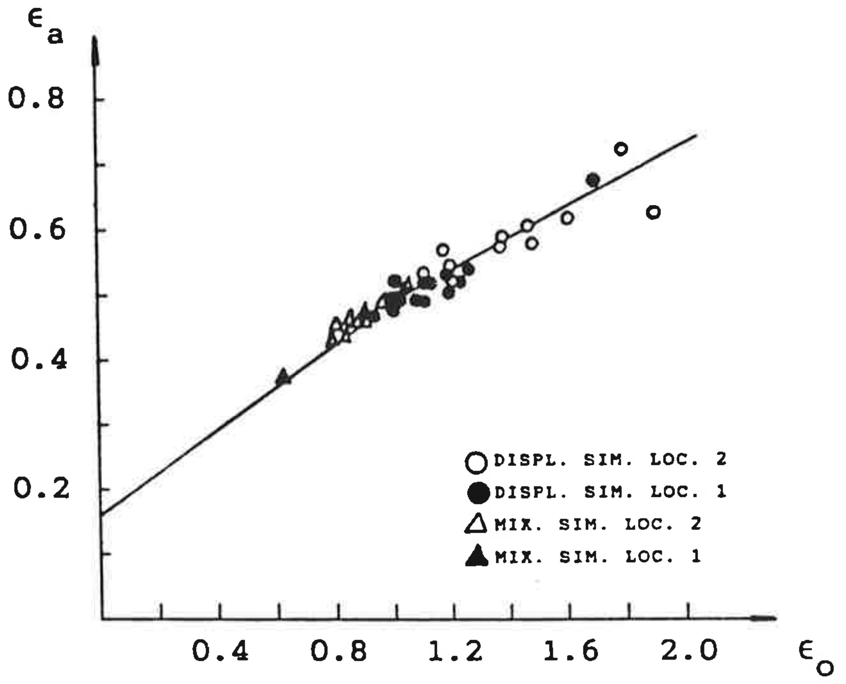
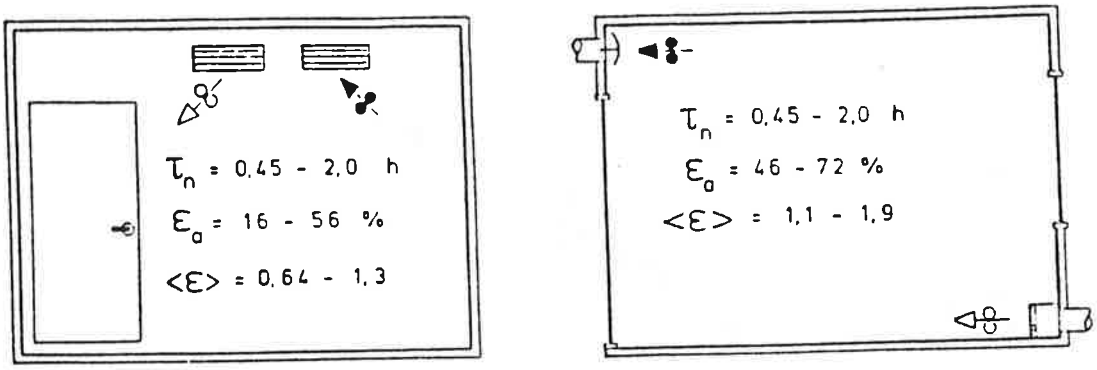
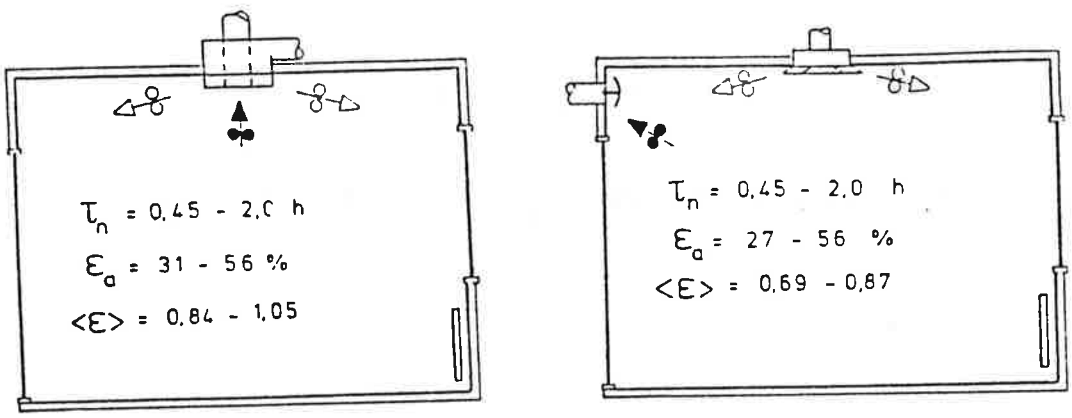


Figure 7. Relation between ϵ_a and ϵ_o in the measurements.



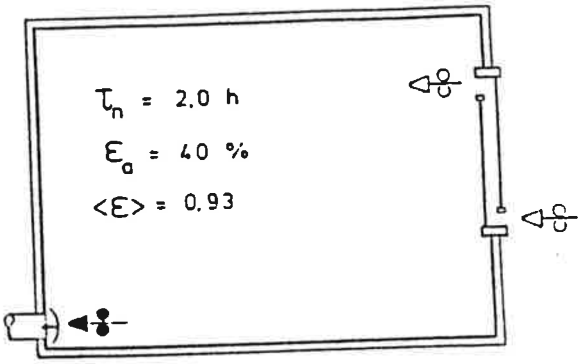
8a. Wall registers.

8b. Displacement ventilation system.



8c. Combined supply and exhaust.

8d. Ceiling diffuser.



8e. Supply trough window.

Figures 8a-8e. Results of measurements with various ventilation patterns.