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Ventilation and temperature efficiencies of Mechanical Ventilation Systems

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ABSTRACT

This paper presents measurements of the ventilation as well as the temperature efficiency of mechanical supply and exhaust systems (balanced systems). The ventilation efficiency is a measure of the performance of providing air in the occupied zone and is also an indicator of the air quality. The temperature efficiency is a measure of the system's capability of supplying heat in the occupied zone. The ventilation efficiencies have been monitored by adopting tracer decay technique and the temperature efficiencies by measuring the stationary temperatures. In experiments the following quantities have been varied systematically:

o The positioning of the supply and exhaust registers

o The ventilation air flow rate

o The temperature of the supply air relative to the mean temperature in the occupied zone.

The findings show significant differences in performance between different systems.

RESUME

Ce mémoire présente des mensurations de lèfficacité de la ventilation et de la température de la ventilation à alimentation ainsi que de l'extraction contrôlée (systèmes équilibrés). L'efficacité de la ventilation est une mesure du rendement de l'adduction d'air dans la zone d'occupation et est également un indicateur de la qualité de l'air. L'efficacité de la température est une mesure de la capacité du système d'adduction de chaleur dans la zone d'occupation. L'efficacité de la ventilation a été analysée en appli-

quant la méthode "tracergas" et l'efficacité de la température en mesurant la température stationnaire. Au cours des expériences les quantités suivantes ont été systématiquement variées:

o Le placement de la bouche d'alimentation et celle d'extraction

o La quantité du flux d'air de ventilation

o La température de l'air d'alimentation relative à la température moyenne dans la zone d'occupation.

Les résultats démontrent des différences importantes de rendement entre les différents systèmes.

INTRODUCTION AND DEFINITIONS

In a warm air system the ventilation system has a dual scope. It shall both provide 'fresh' air as well as heat in the occupied zone. The need of energy concervation requires that we keep the supplied air flow rate as low as possible without conflicting with the requirements on a sufficient air quality. This give rise to the question of measuring the actual ventilation air distribution and heat distribution and defining a measure of the system's efficiency in fulfilling its task.

Ventilation efficiency

The definition used should express the system's ability to remove a pollution originating from a source in a room. In general by using values of the steady state condition, a stationary relative ventilation efficiency $\bar{\varepsilon}^s$ in the occupied zone may be defined as (per cent):

$$\bar{\varepsilon}^s = \frac{C_f - C_t}{\bar{C}_r - C_t} \times 100 \qquad (1)$$

Where C_f is the concentration in the exhaust air duct, $\bar{C}_r$ is the mean concentration in the occupied zone and C_t is the concentration in the supply air duct.

The definition (1) is 'source dependent', i.e. the efficiency varies depending on the position and properties of the source. In our approach we have adopted a source independent definition of the ventilation efficiency, see section Methods for measuring the ventilation efficiency.

Temperature (thermal) efficiency

A ventilation systems ability to supply or remove surplus heat, may be expressed by a temperature (thermal-) efficiency, $\bar{\varepsilon}_T$, similar to definition:

$$\bar{\varepsilon}_T = \frac{T_f - T_t}{T_r - T_t} \qquad (2)$$

T denotes temperature.

As for definition (1) it holds that $\bar{\varepsilon}_T$ may be greater than 100%. A small temperature difference between the supply air temperature and the temperature in the occupied zone implies a high degree of utilization of the pro-

vided energy. The temperature efficiency is however not defined at adiabatic conditions, i.e. when $T_r = T_t$.

In spite of the formal similarities between the definitions (1) and (2), we must keep in mind that there are physical differences between temperatures (heat) and pollutant concentrations. Heat, but not mass, is normally transferred through floors, walls and ceilings.

METHODS FOR MEASURING THE VENTILATION EFFICIENCY

The ventilation efficiency can be determinated in two different ways:

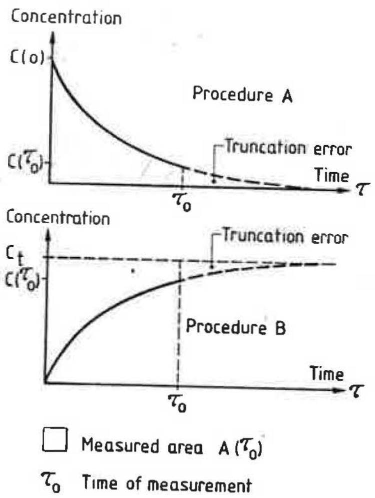
- *Direct method* in which experiments are carried out to simulate conditions under which the ventilation system is to operate either in the building or in a mock-up. The stationary pollutions concentrations are quantified and inserted in definition (1).

- *Indirect method.* By using tracer gas technique a local ventilation rate is determinated. Alternative methods:

  - Procedure A (Decay method). The room is filled with tracer gas. With the aid of fans the gas is mixed to an even initial concentration C(0). The fans are turned off and the decay of the tracer gas is continously recorded at different points.

  - Procedure B. A constant flow of tracer gas is admitted to the supply air duct, i.e. the concentration in the supply air duct C_t is held constant. The increase of the tracer gas concentration is continously recorded at different points.

With the aid of the *area* 'under' the curves, see figure 1, may a *local ventilation air rate* n_j be determinated. Please, observe that in general the slope of the curve in a graph of log concentration versus time can not be used for defining a local ventilation rate. This is thoroughly discussed in (1) and also in (2) and (3).



	A	B	
$n_j =$	$\frac{C(0)-C(\tau_0)}{\hat{A}(\tau_0)}$	$\frac{C(\tau_0)}{\hat{A}(\tau_0)}$	$[\frac{1}{s}]$ or $[\frac{1}{h}]$

Figure 1. Measurement of the local ventilation rate n_j by Procedure A or Procedure B.

By taking the ratio between the local ventilation rate (n_j) and the nominal ventilation rate*) (n) we get the transient relative ventilation efficiency ε^t:

$$\varepsilon_j^t = \frac{n_j}{n} \times 100 \qquad (3)$$

The local ventilation rate is an indicator of the system's ability to evacuate pollutions in the actual part of the room because the following relation holds between the local ventilation rate and the stationary concentration C^s from a homgeneous pollutant source, see (1).

*) The nominal ventilation rate is defined as the supplied air flow rate to the room divided by the volume of the room.

$$C_j^s = \frac{\partial \dot{m}}{n_j} \qquad (4)$$

$\partial \dot{m}$ is the pollution generating rate in kg/m^3s from a pollutant source that is uniformally distributed (homogeneous) over the whole room volume.

Relation (4) shows that for a homogeneous pollutant source the stationary and the transient ventilation efficiencies are equal.

MEASUREMENTS

Measurements have been carried out in a room measuring (width x length x height) = 3.6 x 4.2 x 2.7 m. The occupied zone is defined as the volume up to 1.8 m above the floor. The placing of both the supply and exhaust air registers were varied and both the supply air flow rates and temperatures were varied. The transient relative ventilation efficiencies were measured by adopting tracer gas technique (Procedure A). The temperature efficiencies were obtained by measuring the stationary room temperatures at about fifty points.

System A

In this system the supply as well as exhaust air registers were placed above the occupied zone. This system is a typical short-circuiting scheme or undirectional air flow system. Regarding the transient ventilation efficiency the best we can achieve is to disperse the supplied air uniformly in the occupied zone, i.e. complete mixing (100% efficiency) is the best feasible. The results obtained are shown in figure 2.

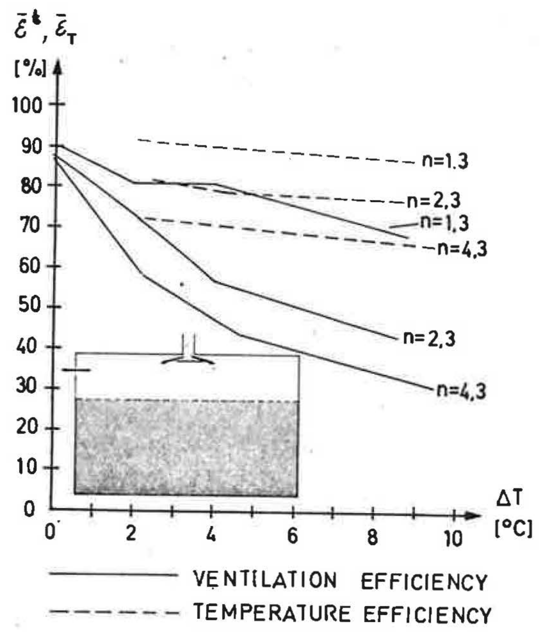


Figure 2. Measured values of the transient relative ventilation efficiency and the stationary temperature efficiency. ΔT is the overtemperature in the supply air relative to the mean temperature in the occupied zone.
n is the nominal air change rate.

Figure 2 show a heavy thermal stratification effect with an increase in the supply air temperature. The increase in the nominal air change rate affects the ventilation efficiency in a perhaps somewhat unexpected manner. The ventilation efficiency decreases when the ventilation air flow is increased.

The temperature efficiencies show a similar pattern.

<u>System B</u>

In this system the exhaust register has been moved to the floor level. With this placing of the supply and exhaust registers complete mixing is the

poorest operational mode. The result obtained for this system is shown in figure 3.

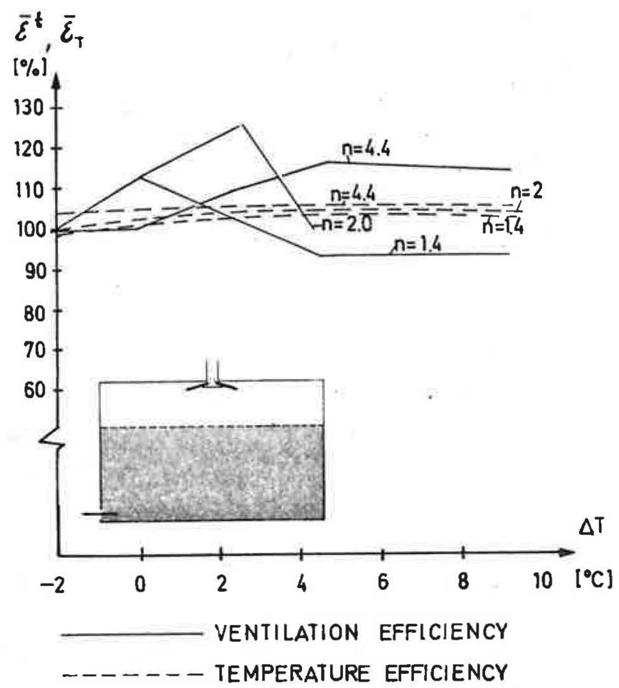


Figure 3. Measured values of the transient relative ventilation efficiency and the stationary temperature efficiency. ΔT is the overtemperature in the supply air relative to the mean temperature in the occupied zone.
n is the nominal air change rate.

Figure 3 shows that we almost always get a ventilation efficiency greater than 100%. Combined high nominal air change rate and high overtemperature give an exceptionally high ventilation efficiency. The explanation is due to the buoyancy effect and placing of the registers. Due to the buoyancy the supplied air sticks to the ceiling, but due to the placing of the registers the air is forced to pass the whole room. The resulting flow is similar to a plug flow.

The temperature efficiencies are always just above 100%.

System C

In this system the air is supplied at floor level next to the wall and is blown vertically along the wall. The exhaust air register is placed in the middle of the ceiling. This is again an undirectional air flow system and we should expect an ventilation efficiency greater than 100%. The obtained results are shown i figure 4.

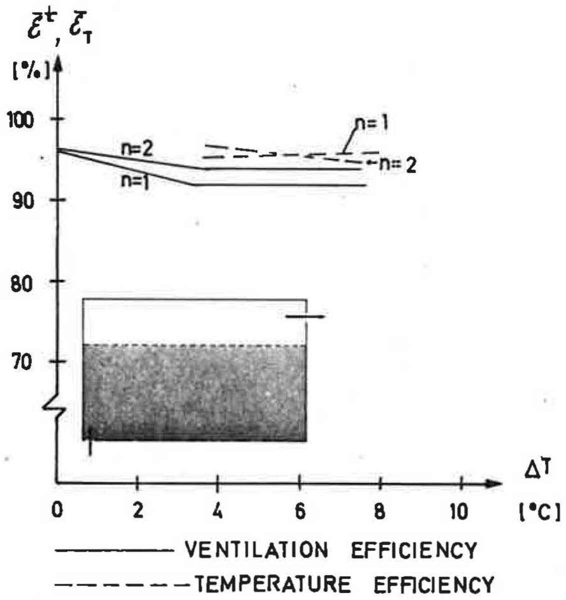


Figure 4. Measured values of the transient relative ventilation efficiency and the stationary temperature efficiency. ΔT is the overtemperature in the supply air relative to the mean temperature in the occupied zone.
n is the nominal air change rate.

Figure 4 shows that we get a ventilation efficiency less than 100% which is

less than the expected efficiency. The explanation is probably a short-circuiting effect due to the fact that the supplied air partly goes as a wall jet flow directly to the extract air register.

The temperature efficiency is however about 100%.

System D

The placing of the registers are the same as for system D, but now the supplied air is blown horisontally along the floor. The results obtained are shown i figure 5.

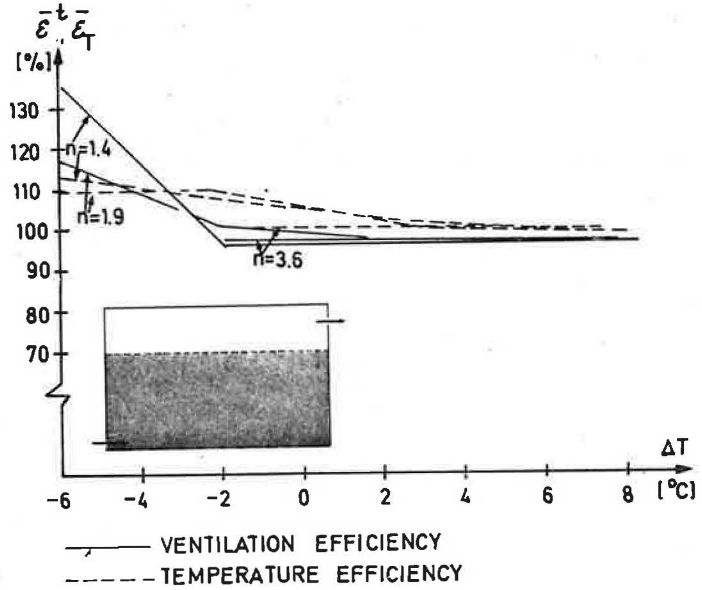


Figure 5. Measured values by Procedure A of the transient relative ventilation efficiency and the stationary temperature efficiency. ΔT is the overtemperature of the supply air relative to the mean temperature in the occupied zone.
n is the nominal air change rate.

Figure 5 shows that in case of cooling the ventilation efficiencies becomes much greater than 100%. The explanation is the same as when system 2 is run as a warm air system, it can be ascribed to the buoyancy effect and the placing of the registers.

The behaviour of the temperature efficiencies show a similar pattern but is less salient.

CONCLUSIONS

Ventilation efficiencies

The tests shows that the ventilation efficiencies vary considerably between different ventilation systems depending on the supply temperature and the placing of the registers. Systems with the registers mounted far apart give both higher efficiencies and more stable air movements than systems with registers mounted close to each other.

The best efficiencies are obtained with the supply- and exhaust registers mounted far apart and when the air is supplied in a direction opposite to the acting thermal forces. This implies for a warm air system that the air should be supplied via a register in the ceiling, while the air should be evacuated at floor level. When cooling is necessary the best efficiency is achieved with the air supply register near the floor and the exhaust register mounted in the ceiling.

Warm air systems with the supply as well as the exhaust registers mounted in the ceiling give rise to a large short-circuiting effect.

Temperature efficiencies

The temperature efficiencies show much less variations than the ventilation efficiencies. The temperature efficiencies are always closer to 100% than the corresponding ventilation efficiencies. Significant temperature gradients appear in the occupied zone only when the air is supplied in a direction opposite to the acting thermal forces.

FUTURE WORK

In a continuation and extension of the project we intend to measure in as well as empty as occupied rooms:

- Ventilation efficiencies
- Temperatures and temperature efficiencies
- Velocities (mean velocities, standard-deviation, frequency spectra, the probability distribution of the amplitude)

ACKNOWLEDGEMENTS

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References

/1/ Sandberg, M., What is ventilation efficiency? Building and Environment, Vol. 16, No 2, 1981, pp 123-135.

/2/ Sandberg, M. & Svensson, A., Measurements of the ventilation efficiency by using the tracer gas technique. To be published in - Building Services Engineering & Technology, 1981.

/3/ Skåret, E. & Mathisen, H.M., Ventilation efficiency, International symposium on 'Indoor Air Pollution, Health and Energy Conservation', Amherst, USA, 1981.