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VENTILATION OF LARGE MILITARY GARAGES AND HEATING WITH IR RADIATORS. EXAMPLES AND ECONOMIC ASPECTS.

Klas Ancker

Swedish Environmental Research Institute

Stockholm, Sweden

SUMMARY

Different ways of ventilating large military garages were studied. The study was prompted by complaints from soldiers and officers concerning exhaust gases from vehicles driven out of or into the garages.

This type of military garage is only used once or twice a day, and sometimes not at all for several days. Nevertheless, the Swedish Construction Code prescribes an exhaust air flow rate of at least 0.9 l/s per m^2 floor space when premises are ventilated by fans. In this case, this seems both unnecessary and expensive.

We found that these highly specialized garages could be effectively ventilated just by leaving the doors wide open - for at least 7 minutes after vehicles had been driven in, and for 10 minutes after they had been driven out of the premises. IR radiators are used only when people are present in the garages, and they provide an effective means for providing good climatic conditions.

The indoor climate was perceived as pleasant and comfortable when IR radiation was used after the garage doors were closed. The IR radiators needed to be on for about 20 minutes to provide a steady-state temperature. Moreover, the total energy cost for heating the garages was only half that of conventional water-heated systems.

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1. Background

Different ways of ventilating large military garages were studied. The study was prompted by complaints from soldiers and officers concerning exhaust gases from vehicles driven out of or into the garages.

The garages are detached buildings; they are used for the parking of vehicles and sporadic maintenance, and occasionally for educational purposes when empty. Some are not heated.

According to the Swedish Construction Code, these garages require ventilation of at least 0.9 l/s per m^2, despite the fact that they are only used sporadically. As they are not in continual use, this results in high costs for ventilation and heating

2. Aim

The study was designed to prepare a proposal for an effective and cheap means for ventilating and heating large military garages.

3. Measuring methods

3.1 General

Two series of experiments were conducted at different places in the garages. Series I examined general questions concerned with the airing times of different types of ventilation, while Series II was used both to verify earlier results and provide comparative measurements. In addition, expenditures of energy on IR heating and conventional heating were compared. A survey of people's perceptions of IR heating was also conducted.

3.2. Measuring techniques

Sample air was led from 3 measuring points in the garages through black PE hoses and via a Regtech multiplexor to the measuring instruments on adjacent premises. Measurements of temperatures within the garages were also taken.

Instrument readings were recorded on a Regtech datalogger. Gas concentration measurements were carried out semi-continuously according to a cyclical measuring schedule. Nitrogen monoxide (NO) was used as tracer gas for diesel exhaust fumes in Series I, carbon dioxide (CO_2) in Series II. The measurements taken alternated between measuring points, each lasting 5 seconds with a waiting time of 10 seconds. Temperature was measured for a time period of 1 second. Including recording time, each measuring cycle took 1 minute and 47 seconds.

Analyses of NO were carried out using a direct-reading chemiluminescence instrument (Tecan CLD 700 AL); measuring of CO_2 was implemented with an IR instrument (Miran-1A); while some supplementary tests were made for concurrent concentrations of CO, CO_2, NO and NO_2 (experiment 6, page 10). Temperatures were recorded using a Pt-100 instrument equipped with a thermistor probe (Testoterm).

The accuracy of the measurements is estimated at approx. 15% for the entire measuring system, comprising hoses, multiplexor, pumps, measuring instruments and datalogger.

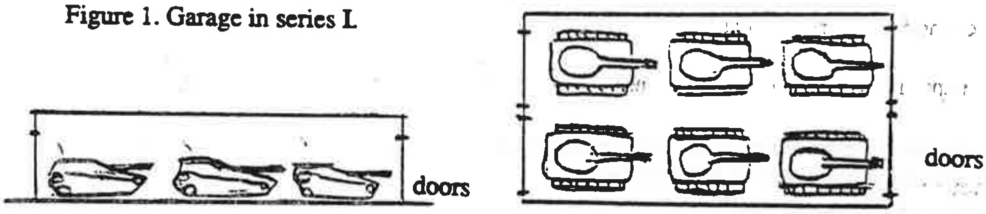
The experiments commenced when vehicles were parked in the garages. Their engines were started and allowed to idle for 1-2 minutes before being reversed out. They were taken out in shifts, there being about three vehicles for each driver.

4. Series I

4.1. Location and other conditions

The experiments were conducted in a vehicle-washing bay approximately 13 meters wide, 25 meters long and 6 meters high, with a total volume of around 2000m³. The bay had two lanes with room for three vehicles in each, providing space for 6 vehicles in total. Both sides of the bay were equipped with wind-up doors so that entrance and exit were possible at both ends (see fig.1).

Figure 1. Garage in series I.



Six tanks, each powered by a diesel engine with a cylinder volume of 5.2 liters, were used for the experiments. Standard diesel fuel was used. During the experiments, all 6 tanks were moved in and out of the garage.

4.2 Experimental design

Different ways of moving the vehicles and different ventilation methods were investigated. It was assumed that the garage doors were first opened just before a vehicle entered or left the garage. The doors were then *left open* while airing took place.

Tests for the following were made.

A. Passive (natural) **ventilation:**

A1. Measurements were taken to compare the case where a vehicle was reversed out and driven in with that where one was driven out and reversed in.

As the *reversing-out* and *driving-in* combination gave distinctly lower exhaust concentrations, further measurements under a variety of conditions were taken only for this case.

A2. With a 1 meter (floor or ceiling) ventilator slot in the wall opposite the doors, i.e. at the far end of the garage.

A3. With the doors open at both ends of the garage, creating a draught.

B. Active ventilation:

B1. Under general ventilation conditions (with ventilation supply and exhaust air through the ceiling) for the case where vehicles were driven in and the doors closed immediately. Only one measurement was taken for this case.

B2. When a single powerful fan was *extracting* exhaust gases from the garage while the doors were still open. Experiments were conducted with the fan near the floor and near the ceiling, at the far end of the garage. The fan had a capacity of $5700 m^3$/hour, giving an air change rate of approx. 3 times/hour under ideal conditions.

B3. As B2 above, but with the rotation of the fan reversed, so as to *blow in* fresh air.

Due to the limited time available for the experiments, only 1-3 measurements were taken under each set of conditions.

4.3 Measuring points

Four measuring points were set up in the vehicle-washing bay (see fig. 2):
NO was measured at:
-**P1** 2 meters from the doors, 1,7 meters above the floor.
-**P2** 2 meters from the innermost wall, 1,7 meters above the floor
(in one case near the closed doors opposite the open doors used for entrance).
-**P3** 1 meter below the ceiling in the middle of the hall.

Temperature was measured at:
-**T1** along one of the long sides in the middle of the bay, 1,8 meters above the floor.

Results

Since few measurements were taken for each experiment (especially for Series I) entirely reliable conclusions cannot be drawn in all cases. The airing time has been estimated subjectively and visually from the diagrams. The airing time has been treated as the period elapsing between the occasion of maximum NO concentration and a return to the background concentration value, i.e. when exhaust fumes have been virtually completely evacuated from the premises.

Table 1. Airing times for Series A (*passive* ventilation only)

Experiment	Ventilation	Time (minutes)	MV±SD	number (=n)
A1 reversing out	passive	8; 6; 8; 9	7,8 ± 1,3	4
A1 driving in	-"-	8; 6	7,0 ± 1,4	2
A1 driving out	-"-	11; 12	11,5 ± 0,7	2
A1 reversing in	-"-	14	14	1
A2 driving in	passive with slot near ceiling	10; 9	9,5 ± 0,7	2
A2 reversing out	-"-	8; 9	8,5 ± 0,7	2
A2 driving in	passive with slot near floor	10; 12	11,0 ± 1,4	2
A2 reversing out	-"-	13; 15	14,0 ± 1,4	2
A2 driving in	with draught	5; 4	4,5 ± 0,7	2
A2 reversing out	-"-	4; 3	3,5 ± 0,7	2

In Case **A1** (passive ventilation with doors open) we compared *reversing out* and *driving in* with *driving out* and *reversing in* (see table 1). The average airing times were 8 and 13 minutes respectively. Reversing in also takes longer, meaning that even more exhaust fumes are emitted in the hall. Thus, for all further experiments **(A2 - B3)**, ***the vehicles were reversed out and driven in.***

Case **A2** (*passive ventilation with a 1 meter ventilator slot* at the far end of the garage) shows that airing takes longer when the slot is placed near the ceiling rather than near the floor. Airing times were *no lower* than when there was no slot at all.

In Case **A3** (passive ventilation with all doors open) *a draught* is created. This provides for fast airing and lower maximum concentrations. The air flow is much greater than in other cases. This proved to be the best way of ventilating the premises.

Table 2. Airing times for Series B (with active ventilation)

Experiment	Ventilation	Time (mins)	MV±SD	number (=n)
B1 driving in	with closed doors	>90	>90	1
B2 driving in	fan extracts (near floor)	8; 8	8,0 ± 0,0	2
B2 reversing out	-"-	7; 7	7,0 ± 0,0	2
B2 driving in	fan extracts (near ceiling)	8	8	1
B2 reversing out	-"-	11	11	1
B3 driving in	fan blows in (near floor)	14; 14	14± 0	2
B3 reversing out	-"-	12	12	1
B3 driving in	fan blows in (near ceiling	13	13	1
B3 reversing out	-"-	12	12	1

In Case **B1** (active general ventilation with closed doors) a long time is required to air the premises despite a relatively low maximum NO concentration. The air change rate is 0,3 per hour, giving an average airing time of over three hours. The general ventilation was probably either performing poorly or out-of-order on this occasion.

In Case **B2** (active ventilation with *supplementary* fan - extracting) an extra fan was moved between the floor and the ceiling at the far end of the hall. When the fan is used for extraction of air at floor level, there is no clear difference between cases **B2** and **A1**.

In Case **B3** (active ventilation with supplementary fan - blowing) the extra fan was used to blow air into the premises. The airing rate was lower and concentrations were higher. If air is blown in, whatever the position of the fan, the ventilation is *impaired*.

4.5 Discussion

Airing should be made to work according to **the displacement principal** to the greatest extent possible. A steady displacement of air with no whirling recirculation seems to be the most effective way of disposing of air containing exhaust fumes. This can be achieved by raising the garage temperature slightly above that of outdoor air. The relatively colder fresh air will then enter the garage at floor level and the polluted air will rise towards the ceiling. The air nearest the ceiling is also the most polluted, both because exhaust pipes are directed upwards and since the warmth of the exhaust fumes forces them to rise.

The draught experiments show that a rapid air flow can lead to a very short airing time and low maximum concentrations. The experiments demonstrate that a draught will lead to *a shortening* of the airing time.

The airing time increases and the ventilation is impaired if air is blown in with a fan, i.e. if the air is *mixed* in the garage.

The following factors *impair* the ventilation: a) the same temperature in the garage as outdoors, b) fans blowing in fresh air, mixing the air inside the premises.

Some factors, such as a floor-level ventilator slot, seem to have only a marginal effect on ventilation. Ventilation efficiency probably increases with increased wind speed outdoors.

It should be specially noted that these experiments were conducted during winter. In the summer, it could be difficult to keep the indoor temperature higher than the outdoor temperature, which is needed to improve the ventilation. However, the doors could then be left open for a longer period, as there is less need to keep the garages heated.

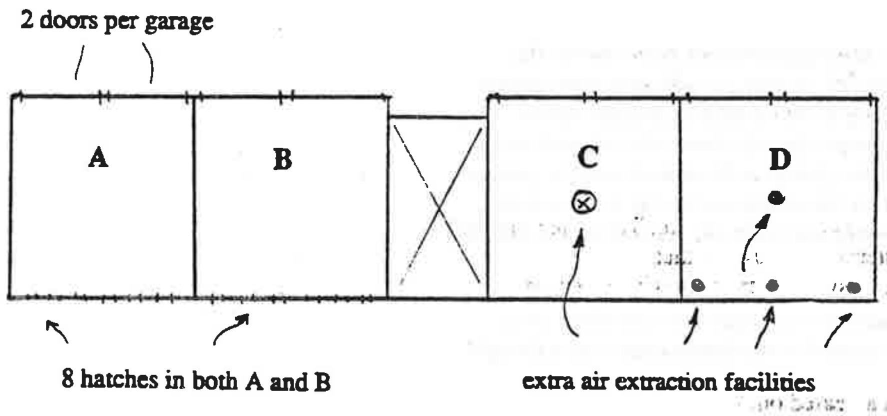
5. Series II

To confirm airing times and establish the effects of open hatches and ventilator slots, additional measurements were carried out in other premises.

5.1 The premises and other experimental conditions.

The experiments were conducted in a row of garages. There were 4 large garages, A, B, C and D (of approx. 24 x 25 meters) grouped in pairs with washing rooms and training facilities in the middle. The average height of the garage ceilings was approximately six meters (see fig. 2). The garages were equipped with different types of ventilation and heating systems.

Figure 2. Garages in series II.



Garage A.

-No active ventilation (no fans), a small ventilator slot which could be opened above the doors and 8 hatches of 1,4 x 1,8 m (2.5 m^2/hatch) at the far end of the garage, located 1,5 meters above the floor.
-Butane-fired, IR-radiating heating coils in the ceiling (surface temperature approx. 400°C).

Garage B.

-*Pre-heated* basic ventilation (approx. 10 °C and 3000 m^3/hour, giving an air change rate of approx. 0,8 /hour) and 8 hatches of similar size and in similar locations to the hatches in Garage A.
-Hot water heating coils in the ceiling with a maximum surface temperature of approx. 60°C, varying with the outdoor temperature.

Garage C.

-Similar pre-heated basic ventilation to Garage B with extra air extraction facilities (approx. 12500m^3/hour) located in the ceiling.
-Hot water heating coils similar to B.

Garage D.

-Similar pre-heated basic ventilation as in B with extra air extraction facilities (approx. 12500 m^3/hour), half of the extraction capacity being located at the ceiling, the other half consisting of three devices at floor-level at the far end of the garage.
-Hot water heating coils similar to B.

No diesel-powered tanks were available at the time of measurement, so the experiments were conducted using 15 other vehicles: 8 diesel-powered trucks and 7 diesel-powered tractors.

Some supplementary experiments were conducted using 6 petrol-engined tanks. These were reversed out of and driven into the garages according to normal procedure, i.e. they were started inside and taken out immediately.

5.2 Experimental design.

The doors were left open during the airing process and then closed. The airing times for a couple of different basic ventilation systems were also studied.
The aim of the measurements was to provide answers to the following questions.

Experiments with doors *open* during airing:

1. Does a cold garage take longer to air than a heated one?
2. What is the influence of a narrow ventilator slot located above the doors?
3. What is the influence of open hatches located at the far end of the garage?
4. What is the influence of a combination of 2 and 3 above?

Experiments with doors *closed* during airing:

5. What airing time is provided by the basic ventilation?
6. What is the influence of a narrow ventilator slot located above the doors?
7. What is the airing time for a heated garage with open hatches at the far end?
8. What is the airing time for a cold garage with open hatches at the far end and a narrow ventilator slot above the entrance doors?
9. What is the influence of increasing ventilation by extracting half of the air at the ceiling and half using three extracting devices at floor level in comparison with all air being extracted at the ceiling.

5.3 Measuring points.

To be able to chart how these factors influenced airing time, exhaust concentration measurements were taken at five measuring points in each garage.

-**P1** was placed 1,5 meters inside the doors, 1,7 meters above the floor.
-**P2** was placed 1,5 meters from the wall at the far end of the garage, 1,7 meters above the floor.
-**P3** was placed in the middle of the garage, 5 meters above the floor.

Temperature was recorded at two points.

-**T1** was placed in the middle of one side of the garage, 0,5 meters above the floor.
-**T2** was placed next to P3.

5.4 Results

The outdoor concentration of CO_2 is approximately 350 ppm on average. In the diagrams, this concentration is given as 0 ppm. The measuring instrument's zero was not constant during measuring, but drifted slightly upwards, by about 100 ppm. For this reason, the CO_2 concentrations shown in the diagrams do not always start or stop at 0 ppm. For reasons of time, only 2-5 airing trials were recorded for each experiment (see table 3).

Figure 3. Series II experiment 6

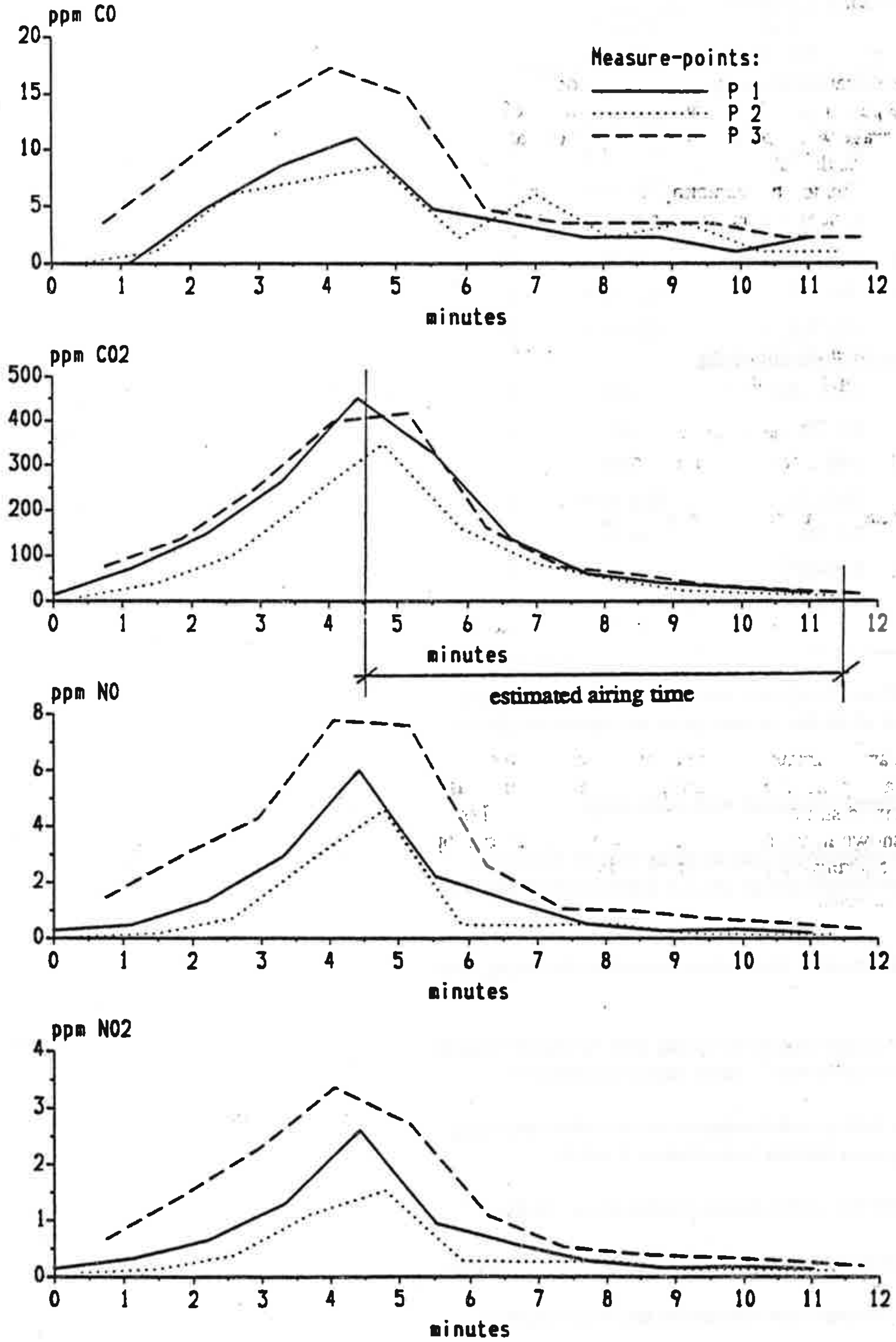


Table 3. Airing times for different conditions i garages A-D.

Experi-ment	Garage	Ventilation	Tid minutes	MV±SD minutes	n
		Open doors during airing			
1	A	none	9; 9; 8	8,7 ±0,5	3
2	A	slot at ceiling	8; 10; 9,5	9,2 ±1,0	3
3	A	hatches	7; 7	7,0 ±0,0	2
4	A	slot + hatches	6; 7; 9; 7,5; 7	7,3 ±1,1	5
5	B	basic ventilation	7; 8; 7; 6; 7	7,0 ±0,7	4
6	C	basic ventilation	6x); 7x)	6,5 ±0,7	2
7	B	hatches	9,5; 7,5; 7	8,0 ±1,3	3
		Closed doors during airing			
8	A	slot at ceiling	>30; >50	>30	2
9	A	slot + hatches	20; 20	20	2
10	B	basic ventilation	>40	>40	1
11	B	hatches	10,5; 11	10,8 ±0.4	2
12	C	suppl. ventilation	12; 20; 22;>18x)	ca 20	4
13	D	suppl. ventilation	33; 27	ca 30	2

x) experiments where CO, CO2, NO and NO2 were recorded on the same measuring occasion. As expected, the behaviour of all the various gases was rather similar (see figure 3).

Table 3 shows the results of experiments conducted with doors *open*:

1. A garage with pre-heated basic ventilation (B) has an airing time of 7 minutes, compared with 8,7 minutes for a non-heated garage (A), i.e. a reduction of about 1,5 minutes (experiments 1 and 5).

2. A narrow ventilator slot above the entrance doors does not reduce the airing time (experiments 1 and 2).

3. Open hatches at the far end of the garage reduce the airing time by about 1 minute (experiments 5 and 6 compared with experiment 7, under similar conditions).

4. Combining a ventilator slot in the ceiling with hatches does not reduce the airing time in comparison with just having open hatches (experiments 3 and 4).

The results of experiments conducted with doors *closed* are also shown in table 3:

5. The airing time of a garage with basic ventilation is >40 minutes (experiment 10).

6. The airing time for a cold garage without basic ventilation but with a narrow

ventilator slot above the doors is >30 minutes (experiment 8).

7. In a *heated* garage where hatches are opened at the far end, the airing time is about 11 minutes (experiment 11).

8. The airing time for a *cold* garage with ventilator slot and open hatches is 20 minutes (experiment 9).

9. A garage with supplementary ventilation, where the extracting devices are placed in the middle of the ceiling, has an airing time of about 20 minutes, compared to 30 minutes for a garage with similar ventilation but where half of the extra ventilation capacity consists of three extraction devices at floor level at the far end of the garage (experiments 12 and 13).

5.5 Experiments with petrol-engined vehicles

The aim of this experiment was to measure the airing time for the "normal" exit and entrance of tanks, that is under non-standardized conditions.

Table 4. Airing times obtained from experiments with 6 petrol-engined vehicles.

Experiment	Garage	Ventilation	Time (minutes)	MV±SD (minutes)	n	Notes.
14	A	passive	5; 5	5,0 ± 0,0	2	driving in
15	A	passive	7; 8	7,5 ± 0,7	2	reversing out

Airing times after reversing out are similar to those found for Series 1. The concentrations after driving in are approx. 1/3 lower than those for reversing out. The procedure is quicker and there is less time for large quantities of exhaust fumes to be emitted.

5.6 Discussion.

A steady displacing air flow without whirling air recirculation seems to be the most effective way of disposing of exhaust fumes. To get air to rise, a difference in temperature is needed; fresh air can then replace contaminated air (which travels upwards and out). A temperature difference of a couple of degrees seems to be sufficient for airing times to be kept under 10 minutes with doors open. There was such a difference in temperature between indoor and outdoor air even when the garages were not heated. The fact that exhaust air is warm also helps to make it rise.

Our experiments show that it was more than twice as effective to keep the doors open during airing than to install supplementary active ventilation facilities (with a capacity of 12500 m^3/hour) in the ceiling. It is questionable whether this latter form of ventilation, i.e. the use of fans to extract occasional concentrations of exhaust fumes, is justifiable in the light of the major investment and maintenance costs it would involve.

No activities are usually taking place in the garages immediately after vehicles are reversed out. In the light of this, a reduction in the airing time to around 5 minutes might be suggested (most of the fumes are removed during the first few minutes). Experiments with petrol-engined vehicles also show that concentrations on ***driving-in*** are not as high, and an airing time of around 5 minutes can also be proposed in this case. This should be tested from case to case. The required airing time should depend on the level of discomfort experienced by people who are present and working within the garage.

6. Conclusions

Exhaust fumes in large garages (25 x 25 m) can be effectively removed by allowing the doors to remain open *for at most 10 minutes* after the last vehicle has been driven out or the last engine switched off. For a mechanical ventilation system to evacuate the fumes as effectively, i.e. for air to be changed within 10 minutes with the doors closed, an air flow through the fans of around 20 000 m^3/hour would be required. The cost of installing such facilities is probably very high, particularly in the light of the fact that the same results can be achieved by leaving the doors open. During our experiments, it was twice as effective to air the garages with doors open as it was to ventilate using supplementary facilities with doors closed (compare experiment 1 with experiments 12 and 13).

Openable hatches (8 hatches, each of 1,4 x 1,8 m), located at chest height at the far end of the garage, shorten the airing time to some extent (around 1 minute) if the garage doors are open. If the doors are closed, hatches opened and the garage *heated*, an airing time of around 11 minutes is obtained, which compares with 20 minutes if the garage is *not heated.*

It is important to be able to heat the garages quickly after airing if people are going to be present in them.

7. Heating costs and comfort

Heating costs for spaces A and B (described in sect 5.1 above) have been compared for the period 1991-01-08 to 1991-03-08, i.e. a period of under 3 months. It emerges that costs and energy consumption are 50% lower for IR oil heating than for conventional forms of heating. This largely depends on the fact that operating times are controlled manually, i.e. when needed, not at other times.

It is calculated that the installation cost for IR gas oil heating would have a pay-off time of around 4 years.

A survey of perceptions of IR gas oil heating was unfortunately not completed. However, over the period November - March, a series of occasional interviews with officers and national servicemen suggested the following:

The system is regarded as *good/very good* because:

1) It provides an immediate perception that the climate is comfortable.
2) It is easy to use.
3) It is effective even after the garage has been aired.
4) No disadvantages can be detected.

It should be pointed out that the outdoor temperature during the trial period was abnormally high (it was a very mild winter). The heating-up time using IR gas oil heaters for Space A was 25 minutes; this compares with about 60 minutes for Space B where water-based heating was used. The heating effect of the gas oil method is 100 kW, compared with 42 kW for the water-based method.

8. Proposed measures

To achieve rapid and effective airing, the following measure is proposed:

Provide ventilation by keeping the doors open after vehicles enter and leave the premises. This will provide an airing time of 10 minutes at most.

However, this way of ventilating the garages demands a heating system that provides for rapid heating after airing has taken place if personnel are to be in the premises immediately afterwards. The tested gas oil IR heating system is both effective and cheap, and highly suitable for light buildings that are in *only occasional* use.