# INTERZONAL AIRFLOW FROM GARAGES TO OCCUPIED ZONES AS ONE REASON FOR BUILDING RELATED ILLNESS: THREE CASE STUDIES USING TRACER GAS MEASUREMENTS

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## ABSTRACT

Tracer distribution measurements were performed to assess pollutant transport from basement garages situated in a commercial building and in two residential buildings, in which the occupants had reported typical garage odors and complained about bad indoor air and typical SBS symptoms. A tracer gas technique (tracer gas $SF_6$, infrared detection) was used in all three buildings to study the contaminant distribution in the buildings. In the commercial building, a leaky HVAC system distributed contaminated air from the garage to other zones of the building. A second reason was a large opening in the encasing wall of the exhaust shaft of the garage. In the residential buildings exhaust fans as well as tightly sealed windows and doors led to interzonal airflow from the garage. The results indicate that faulty construction and insufficient sealing between the garage and the occupied floors can most certainly be a reason for building-related illness. The tracer gas technique applied has proved a good tool for detecting leaks and faulty construction in buildings.

## INTRODUCTION

A great number of health problems in buildings are related to bad air quality. Occupants often report odor annoyance and typical SBS (Sick Building Syndrome) symptoms like headache, sore throat and eye irritation. In many cases it is not easy to identify all the chemicals involved, especially if substances with a bad smell and a low olfactory threshold or mixtures of several unknown substances are involved. Odors may cause health problems and affect overall physical and psychological well-being (1;2). Odors are an important cause of worsening of asthma (3).

A potential cause of building-related health problems can be interzonal airflow from basement garages or underground carparks to other zones of a building which may even be far away from the garage. Pollution spreading between two zones is caused either by a mixing between the air of two zones, or can be due to air flow from one zone to the other induced by pressure-difference. The contaminants are substances emitted by cars, including CO, formaldehyde, PAH's, characteristic odorous components and gasoline fumes.

Tracer gas techniques have been widely used to study the pattern of air flow in buildings in order to identify and solve problems related to air quality and ventilation (4), to characterize interzonal pollution transports (5) and to check that remedial measures have been carried out successfully.

Three typical case histories of interzonal airflow from garages to offices or living rooms in the same building are described. In all the cases typical garage odors, gasoline fumes and health problems had been reported. In all the cases the cause of the complaints was found and the deficiencies, which adversely affected indoor air quality, were corrected.

## METHODS

To simulate the distribution of the real contaminant (i.e. garage air) the tracer gas sulphur hexafluoride ($SF_6$) was used. $SF_6$ proved to be a convenient tracer gas for determining the flow of contaminants in a building (6). After charging the basement garages with a certain amount of tracer gas, automobiles were moved in the garage to reach a more homogenous mixing. The concentration of $SF_6$ was measured by a photoacoustic infrared technique.

In most cases sampling was performed in the middle of the rooms at a height of about 1,5 m. Windows and outer doors were kept closed during sampling.

## RESULTS

### Case No. 1

The one-year old commercial building had an HVAC system with three independent ventilation systems. The building housed offices, various shops, dwellings and a doctor's office on the third floor (fig. 1). Beneath the first floor was a two-storey underground carpark, which was mainly used during the opening hours of the shops (8 a.m. to 6 p.m.). Some months after the opening of the doctor's office the majority of the staff of the doctor's office complained about lethargy, headache, irritation of the eyes and upper airways, lack of concentration and the typical smell of garage air, on some days of the smell of gasoline, too. These symptoms belong to the so called Sick Building Syndrome (SBS). The odor annoyance was noticeable only in one zone of the building. The quality of indoor air was much worse than in the previous doctor's office, which had been situated in an older, naturally ventilated building. These facts gave rise to the assumption that the HVAC system may be responsible for the symptoms.

About 10 minutes after injecting $SF_6$ into the garage air a noticeable increase in concentration of tracergas in the supply air was detected. Tracer gas was measured in the air diffuser at the ceiling of the doctor's office as well as in the room air itself. The concentration of tracergas in garage air about 25 minutes after injecting ranged from 20 - 30 mg/m³; the time dependent concentration in the room air of the doctor's office is shown in figure 3. Concentration measurements in the space above the inserted ceiling showed high concentrations of $SF_6$. An inspection of the the walls revealed an opening of about 100x100 cm in the encasing wall of the exhaust shaft of the garage. The pressure difference between the room and the garage induced interzonal airflow from the garage to the space between the ceiling of the fourth floor and the inserted ceiling. From this space contaminated air infiltrated the air of the doctor's office on the third floor (fig. 1).

The opening in the encasing wall of the exhaust shaft was closed, gaps between the ceiling of the garage and the walls of the exhaust shaft were sealed off carefully with elastic sealants. However, contrary to all expectations, after those remedial measures had been carried out, tracer gas could still be detected in the supply air duct after injection into garage air.



The concentration of $SF_6$ was much higher in the supply air duct directly behind the heat recovery unit than in the extract air duct. Therefore, a short circuit in the heat exchanger, as reported in the literature (7), could not be the reason of the elevated concentrations. As tracer gas could not be found at the air intake louvre, a short circuit of air from the exhaust fume of the garage into the air intake duct could be excluded, too. The results showed that the central air conditioning room had to be the reason for the elevated concentration of $SF_6$ in the supply air. To locate the exact area where the fresh air was contaminated, the air intake duct was perforated at equal distances of about one meter. Afterwards $SF_6$ was added directly to the room air near the intake air duct. As the fresh air was measured at the individual holes, a sharp increase in the concentration of $SF_6$ could be measured at the third hole and all subsequent holes. When the bottom part of the air intake duct was inspected with the help of a mirror, a large opening (5 x 60 cm) was detected in the bottom part of the duct.

The central air conditioning room was situated directly above the garage from which several tubular feedthroughs in the ceiling of the garage led into that room. They were insulated only with PU-foam. Thus considerable amounts of contaminated air were sucked from the garage into the central air conditioning room . As the air supply fan caused underpressure, air from the central air conditioning room was sucked into the air intake duct and subsequently distributed in the building.

After the opening in the air intake duct was closed and the holes between the garage and the central air conditioning room were sealed off, only negligeable amounts of $SF_6$ (< 0,3 mg/m³) were detected in the supply air after charging the garage with tracer gas (fig 4).

### Case No. 2

An apartment was situated directly above a garage, which was used only by the inhabitants of the building (fig. 2). The inhabitants of the apartment complained both about the typical smell of garage air in all rooms of the apartment and about headache, irritation of the eyes and sore throat. Two exhaust fans in the kitchen and the toilet as well as tightly sealed windows and doors led to a noticeable underpressure in all the rooms (the exhaust fans couldn't be deactivated by the occupants).

About 20 minutes after injecting $SF_6$ into the garage a slight increase in the concentration of tracergas could be detected in the air of the living room. The time dependent concentration in the living room is shown in figure 5.

The pressure difference between the garage and the apartment led to a penetration of contaminated air into the rooms. The problem was solved by sealing gaps in the ceiling of the garage with elastic sealants. Additionally, outdoor air inlet pipes were installed in the outer walls of the flat to eliminate the pressure-difference between the garage and the apartment.

### Case No. 3

Case No. 3 was very similar to case No. 2. The apartment was situated directly above a garage. The occupants reported odor annoyance (garage air) and similar symptoms as in case No. 2. An exhaust fan in the toilet of the apartment sucked garage air into the living room. The time dependent concentration in the living room is shown in figure 6.

Contrary to case No. 2, where the concentration of $SF_6$ increased very slowly, the concentration rose sharply. $SF_6$ could be detected in the space under the cast plaster floor in a much higher concentration than in the air of the living room. As in case No. 2 the pressure-difference between the garage and the apartment led to a penetration of contaminated air into the living room.

The problem was solved by the owners of the building without consultating the authors by sealing the ceiling of the garage with a polyester sealant containing styrene, which gave rise to further complaints about the smell of styrene for some time.

## DISCUSSION

There may be several reasons for contamination spreading from garages to other zones of a building. Such reasons may include:

- Air flow induced by pressure-difference, together with small gaps between elements of a building or larger gaps, caused by unsealed cable ducts or tubular feedthroughs.
- Larger openings, caused by faulty construction
- Faulty parts in HVAC systems, leaky ducts
- Exhaust devices without direct outdoor air supply to the rooms
- Short-circuits of ventilation air

Much more attention should be paid to the phenomenon of interzonal air flow, especially from garages. Newly built garages near occupied rooms should be examined to prevent the spreading of contaminants. A guideline for ventilation requirements in buildings recommends exhaust devices in service rooms of buildings, which are to produce underpressure in the rooms (8). This recommendation must be implemented with caution when garages are situated in the same building.

The reported cases suggest that polluted air from garages can be a considerable health risk to the occupants and a cause of SBS symptoms. As buildings are acknowledged as a source of pollution in different national standards (which have led to higher ventilation rates for offices) (9), garages should be considered as a potential source of pollution as well.

Knowledge of air movements within a building can solve several problems connected with the spreading of pollutants. The applied tracer gas method is a good and easily applicable tool to solve problems like those described above as well as others (10).

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Fig. 1: Case No. 1

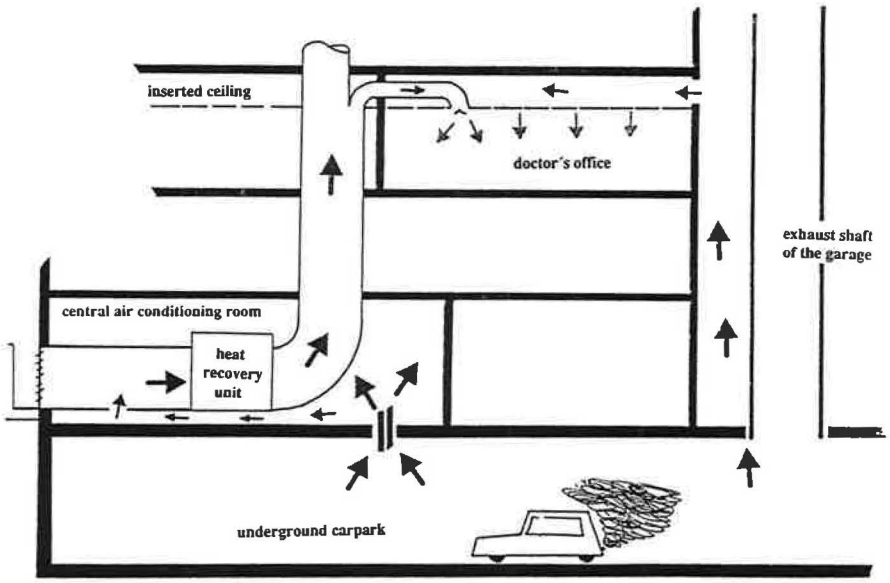

Fig. 2: Case No. 2

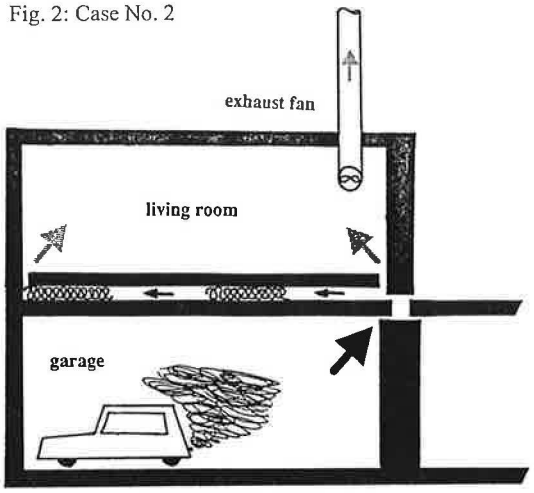


Fig. 3: concentration of tracer gas, case No. 1, room air in doctor's office before sealing

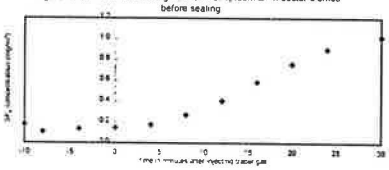

Fig. 4: concentration of tracer gas, case No. 1, supply air in doctor's office after sealing

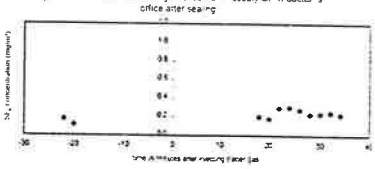

Fig. 5: concentration of tracer gas, case No. 2, living room

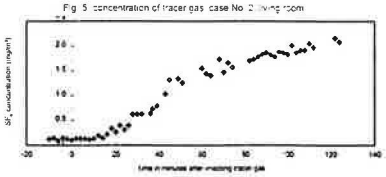

Fig. 6: concentration of tracer gas, case No. 3