INNOVA Sales Training Note
Tracer-gas Measurements

Why use ventilation?

Recent studies have shown a coherence between the quality of the indoor environment and the occupants productivity. Therefore providing a comfortable and healthy indoor environment is of vital importance for the building occupants. Comfort and indoor air quality depend on many factors, including thermal regulation, control of internal and external sources of pollutants, supply of acceptable air, removal of unacceptable air, occupants, activities and preferences. Ventilation and infiltration are only parts of the acceptable indoor air quality and the thermal comfort problem.

The main pollution sources in buildings are the following ones:

- Moisture
- Bioeffluents (body odour, etc.)
- Environmental tobacco smoke
- Radon
- Combustion products
- Volatile organic compounds
- Particulate matter including fibres
- Bioaerosols

The most appropriate method for controlling many indoor air pollutants, including volatile organic compounds, tobacco smoke, particulate matter and radon, is to control it at the source. This may be accomplished either by sealing, or by restricting the presence or the use of such a polluting source.

However, good indoor air quality and energyefficiency are often seen as conflicting aspects in the building design. Indeed, without proper design and engineering, the objective to save energy may deteriorate indoor air quality.

Ventilation and infiltration

Proper ventilation and infiltration airflows in buildings are important for providing comfort for the occupants. Outdoor air that flows through a building is often used to dilute and remove indoor air contaminants. However, the energy required to condition this outdoor air can be a significant portion of the total space-conditioning load. The magnitude of the outdoor airflow into the building must be known for proper sizing of the ventilation system and evaluation of the energy consumption. **Air Exchange** of outdoor air with the air already in a building can be divided into ventilation and infiltration.

Ventilation air is used to provide acceptable indoor air quality. It may be a mix of forced or natural ventilation, infiltration, re-circulated air, or a combination. **Ventilation** includes the intentional introduction of air from the outside into a building. **Natural Ventilation** is air flow through open widows, doors and other planned openings and **Forced Ventilation** (Fig.1) is the intentional movement of air into a building using ventilation systems.

Infiltration (Fig.1) is the flow of outdoor air into a building through cracks and other unintended openings and through the normal use of exterior doors. Infiltration is also known as **Air Leakage** into a building.

Exfiltration (Fig.1) is the leakage of air out of a building through similar types of openings. Like natural ventilation, infiltration and exfiltration are driven by natural and/or artificial pressure differences.

Transfer air (Fig.1) is the air that moves from one interior space to another, either intentionally or not.

These modes of air exchange differ significantly in how they affect energy consumption, air quality and thermal comfort, and they can vary with weather conditions, building operation and use. Although one mode may seem to dominate in a particular building, all must be considered for the proper design and operation of an HVAC system.

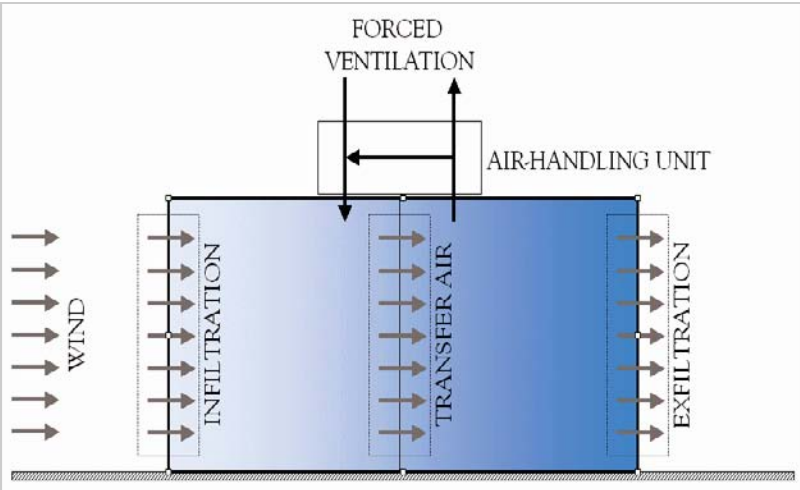

Figure 1. Two-space Building with Forced Ventilation, Infiltration and Exfiltration

Selecting the suitable tracer-gas measurement technique

Desired type of measurement	Air exchange Constant or variable conditions	Number of zones Single/Multi	Selected Method - Constant concentration - Constant emission - Concentration decay	Mixing of tracer-gas with ambient air	Target concentration /dosing nozzel/ initial concentration	Number of sample points
Short term air exchange measurement	Constant	Single zone	Concentration decay	2-4 fans assuring perfect mixing	Initial concentration 50-100 ppm	1 measurement point and 1 or 2 control-points
Long term air exchange measurement	Constant	Single zone	Constant concentration	1 small fan at dosing point	2—5 ppm	1 measurement point control point(s) are not necessary
Guarded measurements—outdoor air exchange measurments	Variable	Multi zones	Constant concentration	1 small fan at each dosing point	2—5 ppm	1 measurement point in each room (zone)
Pollution spreading	Variable	Multi zones	Constant concentration using two tracer-gases	1 small fan at each dosing point	2—5 ppm	1 measurement point in each room (zone)
Age of air	Constant	Single zone	Constant emission	Dosing in ventilation supply air duct, well mixed	Depends on room volume and air flow. Usualy dosing nozzle 1 or 2-5	1 measurment point i ventilation outlet and at point of interest in the room
Flow in ducts	Constant	-	Constant emission	Fully mixed with duct air at sampling point	Depends on volume flow. Usualy nozzle 2-5 is sufficient	1 measurement point and 1 or 2 control points
Guarded measurements—outdoor air exchange measurments	Variable	Multi zones	Constant concentration	1 small fan at each dosing point	2—5 ppm	1 measurement point in each room (zone)

Which Measurement Method to use?

The table on page 2 shows various types of ventilation measurement and appropriate measurement methods and under which circumstances they can be used. The number of fans used for mixing the tracer-gas and the suggested target concentration are only indicative as this depends on the location, number of air exchanges, back-ground concentration or interfering gases.

Air Exchange Rate

The **air exchange rate** compares the airflow to the volume of a space and has the unit; *time*$^{-1}$. When the time is hours, the air exchange rate is also called air changes per hour. The air exchange rate may be defined for several different situations.

The **nominal air exchange rate** is the air exchanges rate for an entire building or zone served by an air handling unit compared to the amount of outside air brought into the building or zone to the total interior volume. The nominal air exchange rate includes both ventilation and infiltration and describes the outside air ventilation rate entering a building or zone. It does not describe recirculation or the distribution of the ventilation air to each space within a building or zone.

The nominal air exchange rate for a zone can be measured using the constant concentration method. In the zone in question and all adjacent zones (rooms) where air exchange may take place with transfer air, the traces-gas concentration is kept at a constant concentration. This means that the calculated air exchange rate is the nominal air exchange rate since it is only influenced by ventilation and infiltration air from the outside .

The Time Constant

The inverse of the air exchange rate is called **the time constant**. One time constant is the time required for one air change in a building, zone or space if ideal displacement flow existed. The **nominal time constant** compares the interior volume to the volumetric outdoor airflow rate.

Like the nominal air exchange rate, the nominal time constant does not describe recirculation of air within a building or zone. It also do not describes the distribution of the outside air to individual spaces within a building or zone.

The Age-of-Air

Age-of-air is the period of time that some quantity of outside air has been in a building, zone or space. The "youngest" air is at the point where the outside air enters the building by forced or natural ventilation or through infiltration. The "oldest" air may be at some location in the building or in the exhaust. When the characteristics of the air distribution system are changed a longer age-of-air indicates poorer outside air delivery compared to a short-age of air for the location. The age-of-air has the unit of time, usually seconds or minutes, so it is not a true "efficiency" or "effectiveness" measure but it can give an indication of problems within a space.

Air Change Effectiveness

Ventilation efficiency is a description of an air distribution system's ability to remove internally generated pollutants from a building, zone or space. **Air change efficiency** is a description of an air distribution system's ability to deliver ventilation air to a building, zone or space. One more common definition of air change efficiency is the ratio of the time constant to the age-of-air.

The **nominal air change efficiency** shows the efficiency of outside air delivery to the entire building, zone or space. The **local air change efficiency** shows the efficiency of outside air delivery to a specific point in a space.

An air change efficiency value of 1.0 indicates that the air distribution system delivers perfectly mixed air in the spaces.

A value of less than 1.0 shows less than perfect mixing with some degree of stagnation. A value greater than 1.0 indicates that a degree of displacement ventilation is present in that point. A value of 2.0 indicates 100% displacement ventilation or piston flow.

Short term air exchange measurement using Concentration Decay method.

The Concentration Decay method is suitable for obtaining small to mid-sized rooms where there are no changes in the ventilation rate during the measurement period, i.e. no opening of doors and windows or changes in the ventilation system. An amount of tracer-gas is released manually and must be fully mixed with the room air using a number of mixing fans that should be running throughout the measurement period. Fully mixing must be assured before the monitoring of the decay is commenced. This can easily be checked by measuring the concentration at 2 or 3 different locations in the room. Provided that no tracer-gas is supplied to the room during the measurement period and the air flow through the room is constant, the concentration will decay exponentially:

$$C(\tau) = C_{start}\ \exp(-N_{\tau})$$

By plotting the natural logarithm of gas concentrations vs. time a straight line is obtained and the gradient of the line is the air exchange rate of the room.

$$\text{Air exchange rate, } N = (\ln C(0) - \ln C(\tau_1))\ /\ \tau_1\ [h^{-1}]$$

Where $C(0)$ = concentration at time = 0
$C(\tau_1))$ = concentration at time = τ_1
τ_1 = total measured period

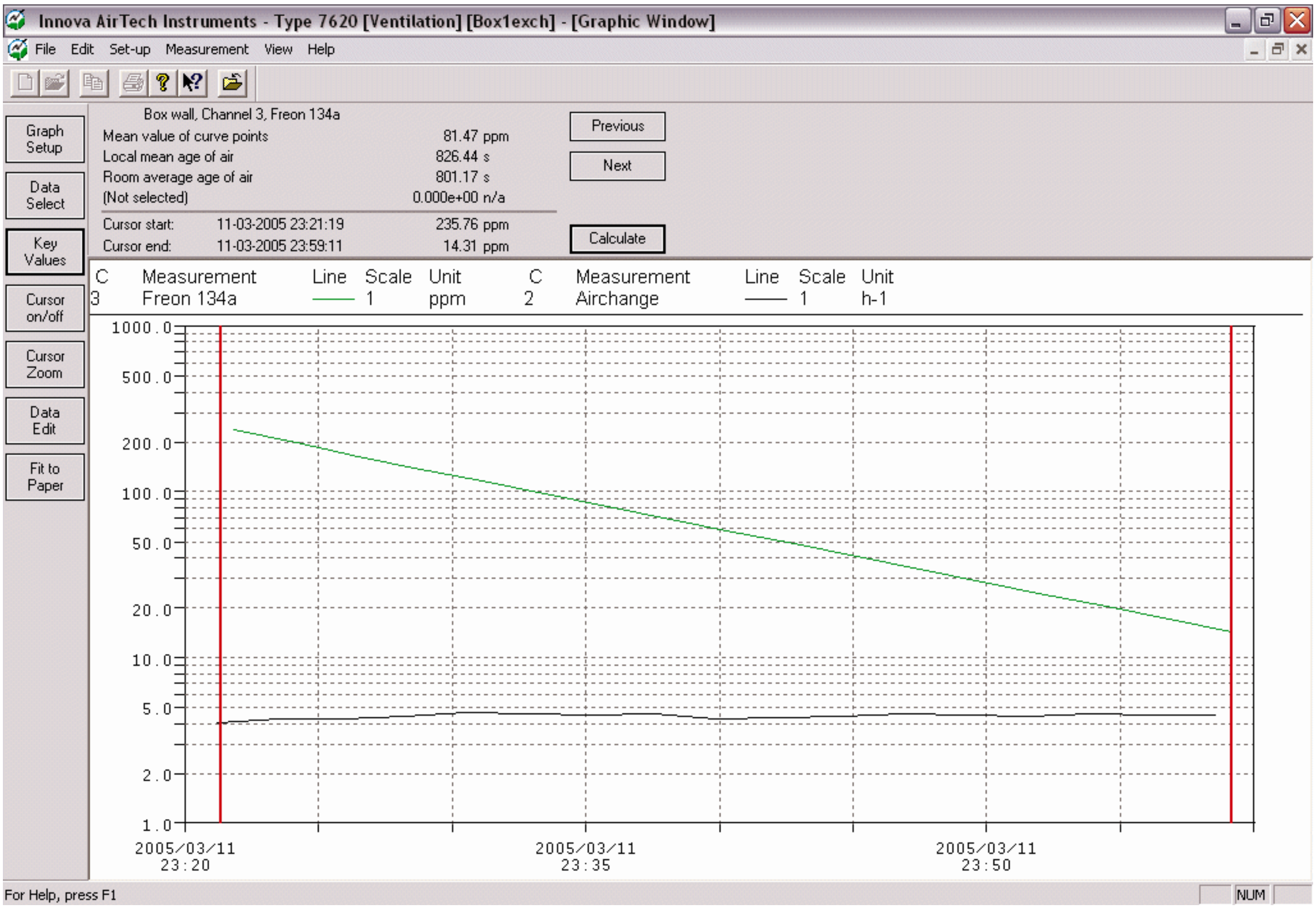

Figure 2. Calculation of air exchange rate (N) based on a decay measuurement in a bathroom . If the air exchange rate is calculated based on the formular, N is 4.44 h^{-1}. Since the Local mean age-of-air is not equal to the Room average age-of-air, the result N = 4.49, based on the inverse of the Room average age-of-air , is not 100% correct.

Long term air exchange measurement in single zone using Constant Concentration method

To study the long term behaviour of a room, the constant concentration method is very useful. In this case the air exchange rate in the kitchen from a single family house kitchen was studied. The dosing point (D1, Fig.3) is placed in the corner of the room with a small fan for mixing the tracer-gas with the room air. No big fans are required as the tracer-gas will mix with the room air during time and it might disturb the air flow characteristics of the room and thus the air exchange when doors and windows are opened. The sampling point (S1, Fig.3) is placed away from the dosing point in order to avoid hysteresis.

The house has been occupied during measurements and the doors have therefore been open in the evening and in the morning, but closed during night time. The air exchange is measured using the constant concentration method, where the software 7620 calculates the necessary release of tracer-gas during time in order to maintain a constant concentration.

The volume of the room (Fig.3) is 74 m3 with a moderate air exchange. The target level of the tracer-gas, R134a, has been set to 2 ppm and dosing nozzle no. 1 is used. From Fig.4 it can be seen that the measurement is most stable at night, this is because occupants activities are low in the period and doors are closed. When there is activity in the evening and in the morning, where the cooker hood is turned on, it can clearly be seen on the air exchange rate.

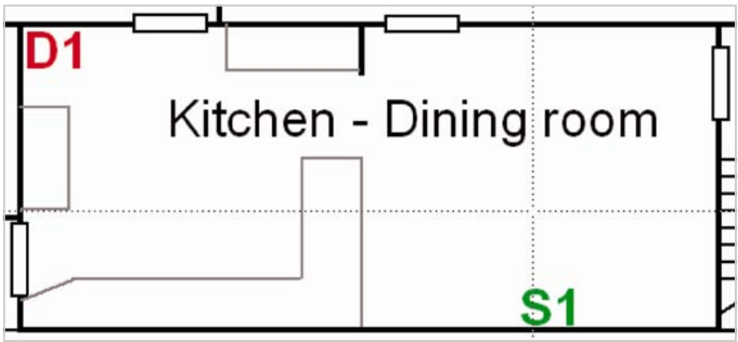

Figure 3. Position of dosing point (D1) and sampling point (S1).

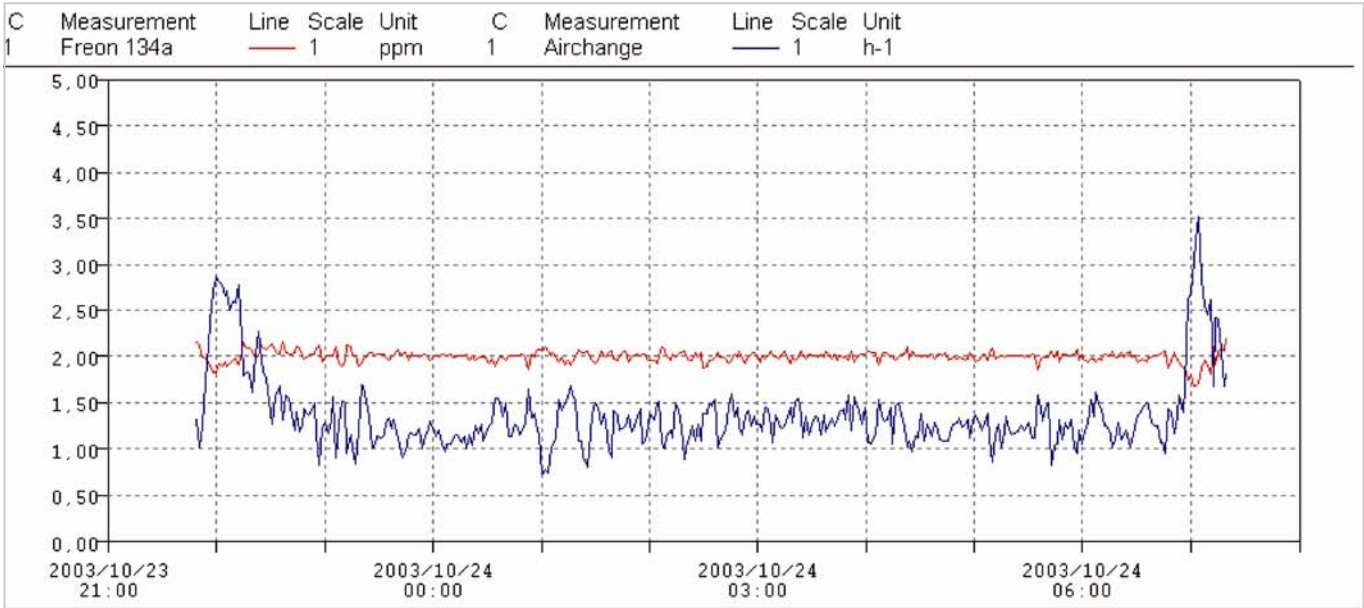

Figure 4. The figure shows :

- *The Freon 134a concentration in the kitchen (channel 1, red line). The concentration is stable at 2 ppm.*
- *The air exchange in the kitchen (channel 1, blue line). The air exchange rate at night is around 1-1.5 h^{-1}*

When using the constant concentration method, selection the correct dosing nozzle on the Multipoint Doser– and Sampler 1303 is very important. The 1303 is fitted with 6 dosing nozzles, each capable of dosing a specific amount of tracer-gas.

- Nozzle no. 1: 0.5 ml/s
- Nozzle no. 2-5: 3 ml/s
- Nozzle no. 6: 15 ml/s

Before using the 1303 it must be calibrated with the tracer-gas used for the measurements. Please note that only pure gas should be used as a tracer-gas. This will ensure that the correct amount of tracer-gas is dosed to the room. If too large a dosing nozzle is selected (Fig.5), in this case nozzle no. 2, the tracer-gas concentration will fluctuate around the desired target concentration, in this case 1.5 ppm. The measurements in Fig.4 and 5 are performed the same room. If too small a nozzle is used the desired tracer-gas concentration might never be reached or it will take long time to reach it.

Figure 5. The figure shows the effect of selecting too large a dosing nozzle on the 1303 compared to the room size and actual air exchange rate. This results in fluctuations of the tracer-gas concentration and therefore also in the calculated air exchange rate.

Guarded measurements – outdoor air exchange measurements using Constant Concentration method

Guarded measurements can be used to measure the air exchange between two parts of a building or to measure the outdoor air exchange. An example of guarded air change measurements is illustrated in Fig.6. The problem is to measure the outdoor air supply rate in the ventilated bathroom which is part of a single family house. The bathroom is called the measured zone and the room next to is called the guarded zone. Measuring the outdoor air exchange of the bathroom can not be done by measuring the air exchange rate in the bathroom as a part of this air exchange will come from the living room next to the bathroom. If the traces gas concentration in the guarded zone is kept at the same level as in the measured zone, air infiltration from the guarded zone to the measured zone will not influence the measurements, and the calculated air exchange rate for the bathroom will be the outdoor air exchange rate.

Fig.7 shows the measurement results where the tracer-gas concentrations is kept at a constant level at 5 ppm in both the living room (red line) and in the bathroom (blue line). The measured air exchange rate in the bathroom can be considered as the outdoor air exchange and is between 0.5 to 1 h^{-1}.

Fig.8 shows the same setup, however, <u>only</u> with dosing of tracer-gas in the bathroom. The measured air exchange rate, consisting of air from outside and from the living room, is around 3 h^{-1}.

Based on these measurement results it can be concluded that most of the air exchange in the bathroom is based on air from the living room and not outside air. This is not a problem as long as the humid air from the bathroom is ventilated to the outside and not to the living room.

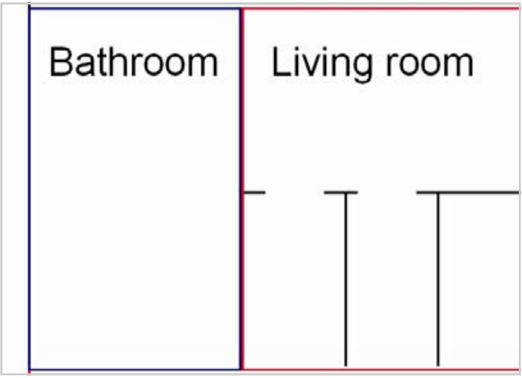

Fig.6 Plan of bathroom and living room.

Since the tracer-gas concentration in the living room (Red curve on Fig.8) is 0.25–0.5 ppm most of the air from the bathroom is ventilated to the outside and will not cause any humidity problems in the rest of the house.

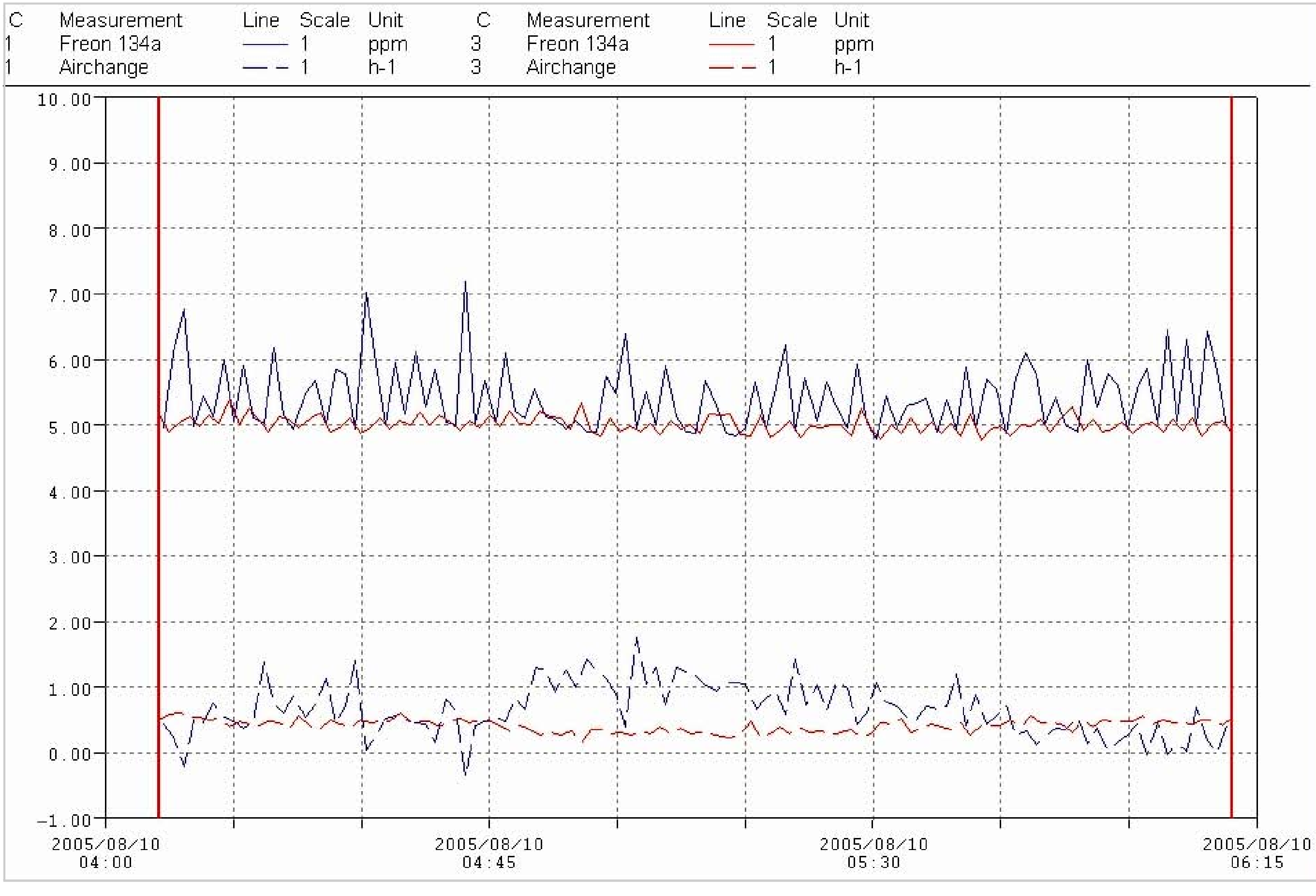

Figure 7. Air exchange measurements with identical concentration in measured– and guarded zone.

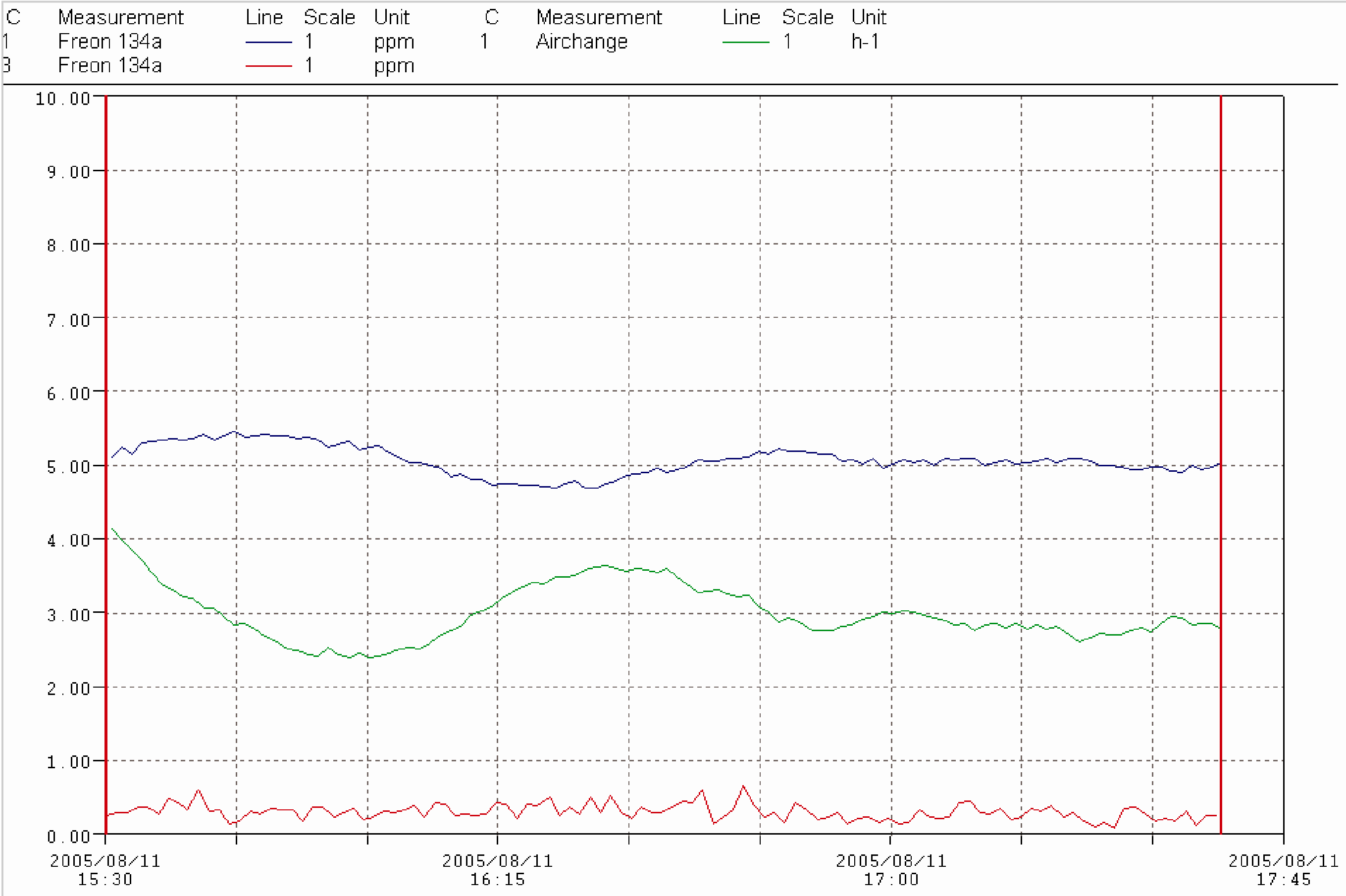

Fig.8 Air exchange measurements with constant concentration in the bathroom (measured zone) only.

Pollution spreading – using Constant Concentration method

In houses humidity and spreading of pollutants, i.e. fumes from kitchens or production processes, can easily be evaluated using either one or two tracer-gases.

In the following example we want to examine the spreading of humidity from the bathroom to the hall in a single family house (Fig.9) using two tracer-gases. In the hall (marked with green) the traces-gas Freon 134a is dosed maintaining a constant concentration of 5 ppm. In the bathroom (marked with blue) SF_6 is dosed maintaining a constant concentration of 5 ppm.

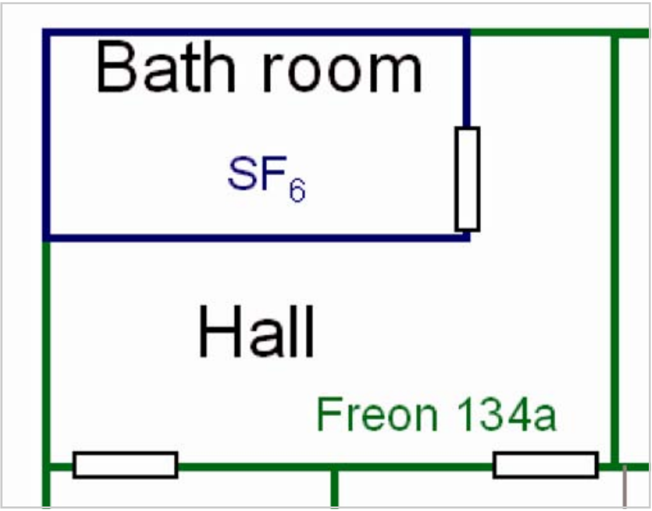

Figure 9. Plan of bathroom and hall

In this way it is possible to see the amount of air moving from the hall to the bathroom and the amount of humid air moving from the bathroom to the hall. The bathroom is equipped with an exhaust fan which was running in the first part of the experiment and turned of at 20:30. As can be seen from Fig.10 the Freon134a concentration in the bathroom is slightly lower that in the hall (where it is dosed). This indicates that the majority of the air exchange in the bathroom is based on air from the hall, rather than fresh air. The door between the two rooms was closed during the period of the experiment. Since there is no fresh air opening in the bathroom this is quite reasonable.

What is more interesting is to examine the amount of air moving from the bathroom to the hall, as this air will contain humidity. Fig.10 shows that the SF_6 concentration in the hall is 0.4 – 0.5 ppm. This indicates that only

10% of the air from the bathroom also enters the hall when the fan is turned off in the bathroom. The air exchange in the two rooms are also calculated. In the bathroom the air exchange is between 3 h^{-1} and 4 h^{-1} and in the hall it is

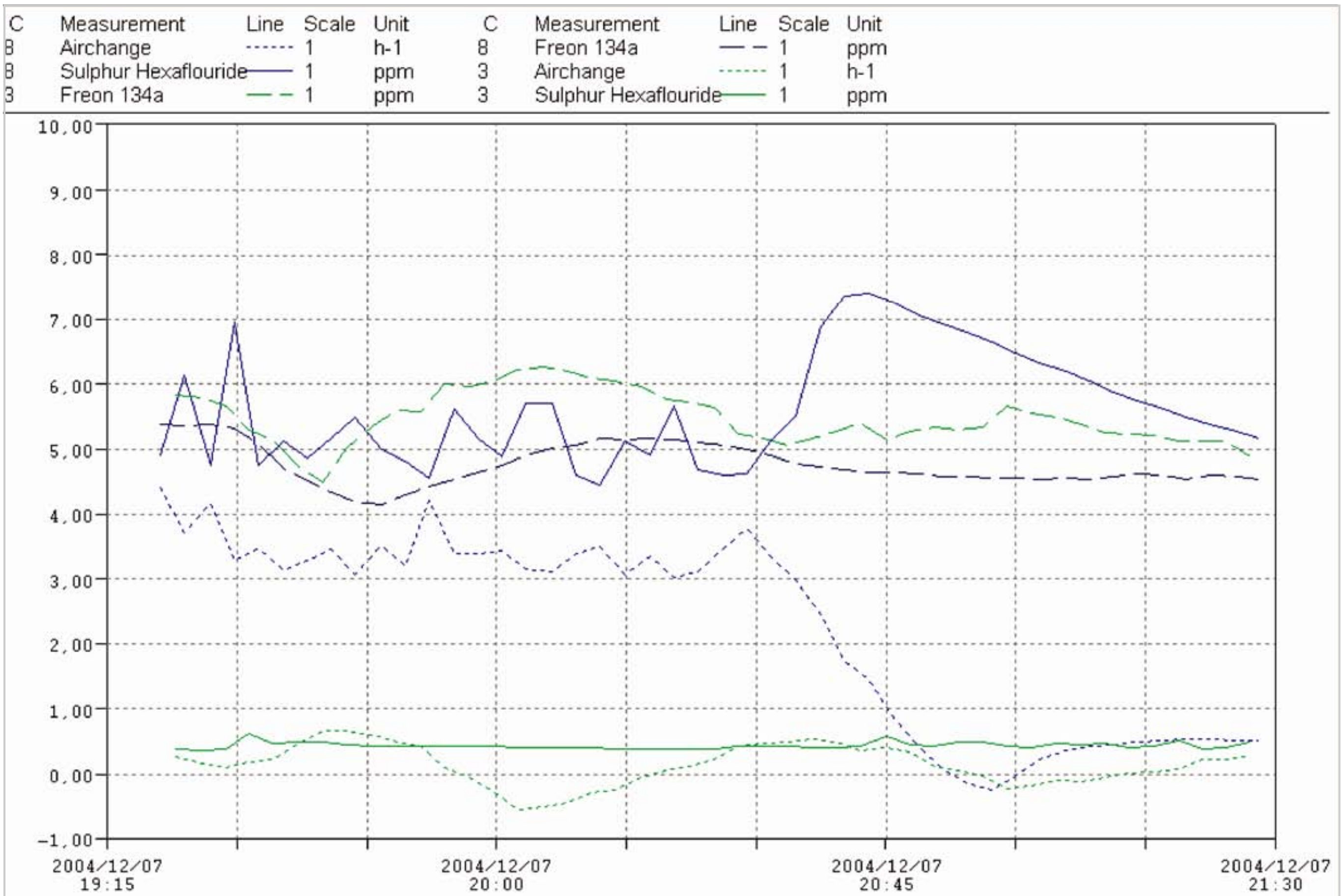

Fig.10 The figure shows the effect of selecting too large a dosing nozzle on the 1303 compared to the room size and actual air exchange rate. This results in fluctuations of the tracer-gas concentration and therefore also in the calculated air exchange rate.

Age-of-air measurements – using Constant Dosing method

These measurements are performed in a single family house with mechanical ventilation. There is supply of air in the living room and air extracts in the kitchen and bathroom. The 6 sample points are placed as follows:

- Channel 1 is placed in exhaust from ventilation unit
- Channel 2 is placed in the air supply to the living room
- Channel 3 is placed in the exhaust from the kitchen
- Channel 4 is placed in the centre of the living room
- Channel 5 is placed in the bathroom
- Channel 6 is placed in internal door between living room and hall
- Tracer-gas dosing point is placed in air supply for the living room

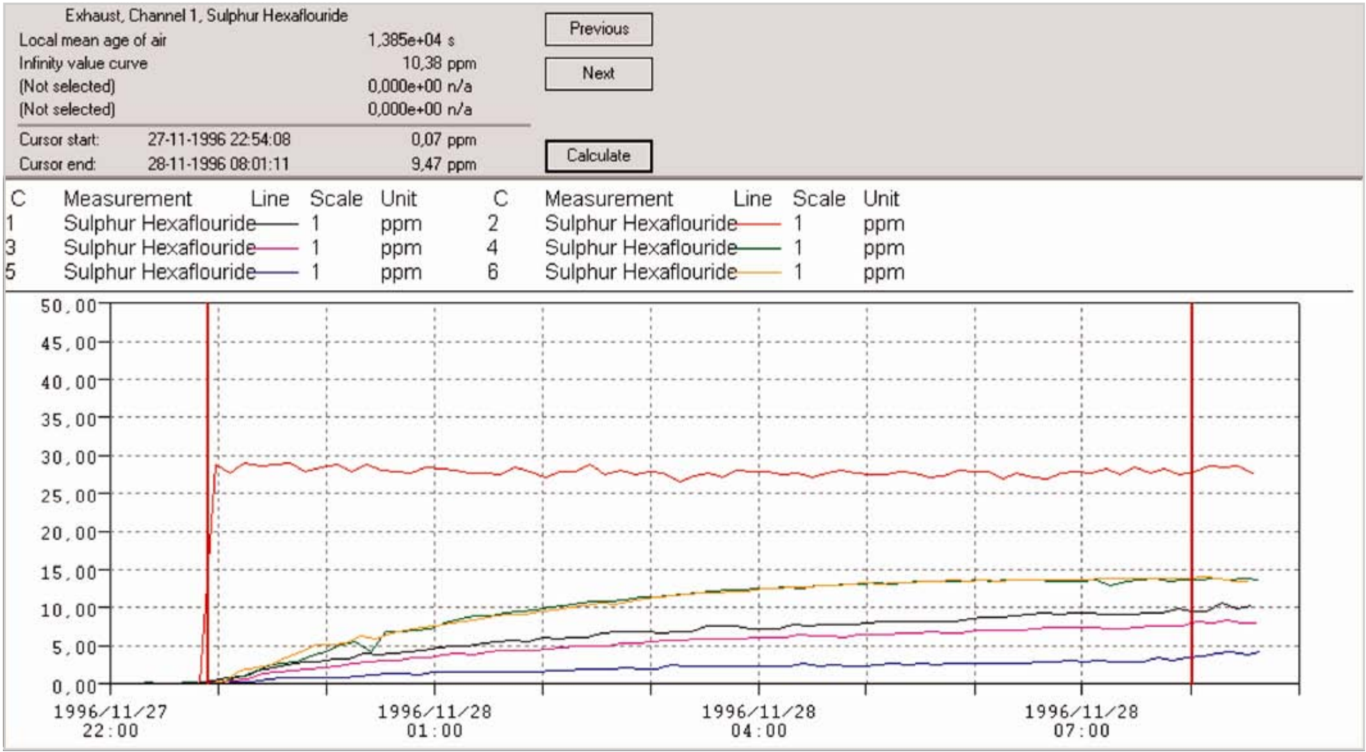

Fig.11. Tracer-gas concentration in various sample points in the house.,

The graph (Fig.11) shows the concentration of SF_6 at the 6 sampling points. Precise 21:55:23 o'clock the emission of tracer-gas is started in the supply air duct and the step-up of the concentration in the 6 sample points is displayed. By use of "key value" the age-of-air and infinity concentration in the individual sample points can be calculated.

The actual data base for 7620 you can find on our homepage under: Extranet/Sales tools/Applications/
The procedure is as follows:

- Place the two cursors as close as possible to 21:55:23 and 7:00:00 o'clock
- Go into "view" and choose "show value"
- Go into the dialogue "Key value" and choose "Local mean age of air", "Infinity value curve", "Over" and "Extrap.". Further more adjust "Fitting" to 100%.
- Calculate and note "Local mean age of air" and "Infinity value on curve" for the curves

The result of the calculations are:

Channel no.	Local mean age of air [seconds]	Local mean age of air [hour]	Infinity value of curve [ppm]	Infinity value in measurement point compared to supply value (27.6 ppm)
1	13680	3.8	10.35	0.38
3	13840	3.8	8.30	0.30
4	9522	2.6	14.33	0.52
5	17810	4.9	3.63	0.13
6	10100	2.8	14.70	0.53

The local mean age of air by a step-up measurement, shows how long time the air supplied by the mechanical ventilation system takes to reach the different sampling points. The table and the figure shows that air reaches the sampling points in the living room most fast, and it takes very long time to reach the sampling point in the bath room (channel 5). This is very natural as all air is supplied into the living room.

By comparing the infinity value of the curve with the tracer-gas concentration in the supply duct, it is possible to calculate how many percent of the air in a sampling point originates from the supply air duct. The part that does not originate from the supply air duct and thus the ventilation system, comes through cracks and open windows or doors. Especially note the fact that only about 40% of the air in the exhaust originates from the air in the supply duct.

Flow in ducts – using Constant Dosing method

The flow in ventilation duct can easily and quickly be calculated using the Constant Dosing method. The dosing and sampling points should be carefully selected in such a way that the tracer-gas is fully mixed with the duct and dosing before any fans, dampers or bends is preferred. To assure that there is a good mixing in the sampling point try to measure in two or three different positions in the duct diameter. The concentration in these points should be close to one another. The volume flow can be calculated as follows:

$$Q_v = \text{Dose [m3/s]} / (C_1—C_0) \ [m_3/m_3]$$

Where.

C_1 = Concentration at the sampling point

C_0 = Background concentration in the duct

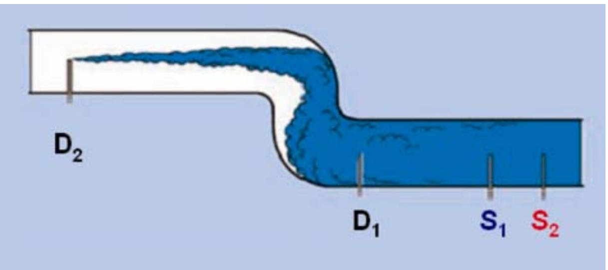

Fig.12. Position of sampling and dosing points in the duct system

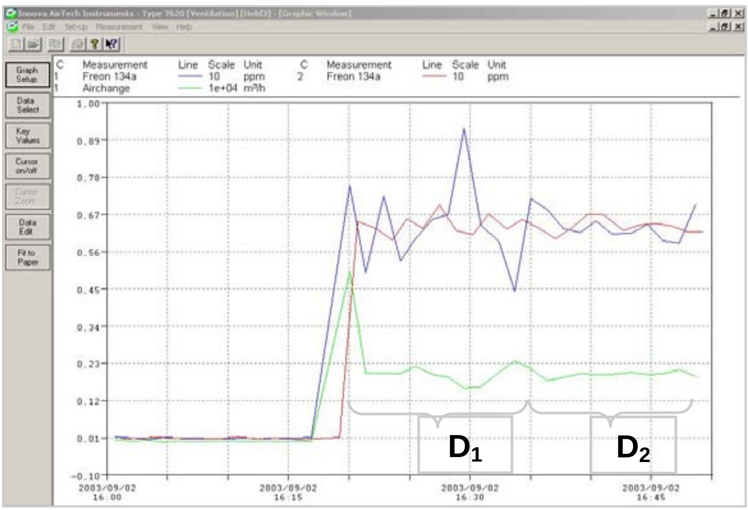

Figure 13. Measurement results from the duct measurements

When performing flow measurements in ducts special attention should be paid to the positioning of both dosing and sampling point inside the duct. The traces-gas must be fully mixed with the air inside the duct at the sampling point. This can be assured by sampling at two different positions in a cross section obtaining an equal and stable concentration.

Fig.12 shows duct measurement results with different position of both the dosing point and sampling point in the duct system. When dosing is done just up-stream the sampling point in a straight duct (D1 and S1) a stable concentration can not be obtained as shown in Fig.13. When the dosing point is moved further away from the sampling point or even better before any bends or other obstacles (D2 and S2) a stable and useable result can be obtained.

The effect of changing the Algorithm settings

In the Set-up/Algorithm menu in 7620 it is possible to change the constants connected to the Kalman Filter (Kl) and the averaging period (Ta). The Kalman Filter's (Kl) function is to remove "noise" from the measurements by damping unreasonable changes in the measured concentrations. However, it slows down the regulation. When Kl=1, the Kalman filter is turned off.

The Averaging Period (Ta) is the time frame window used for the calculation of the air exchange. The air exchange is calculated based on: the gas concentration at the window start, gas concentration at window end, the mean concentration in the window and the mean dose in the window.

If the concentration will not stabilise itself, try to turn off the Kalman Filter and increase the Averaging Period. The reason for turning off the Kalman Filter is that it in some cases might increase fluctuations instead of damping them. If a quick reaction is required, i.e. duct measurements, the Kalman Filter must be turned off and decrease the Averaging Period to 60 or 120 seconds. In Fig.14 results from flow measurements in a duct system are shown, where the al-

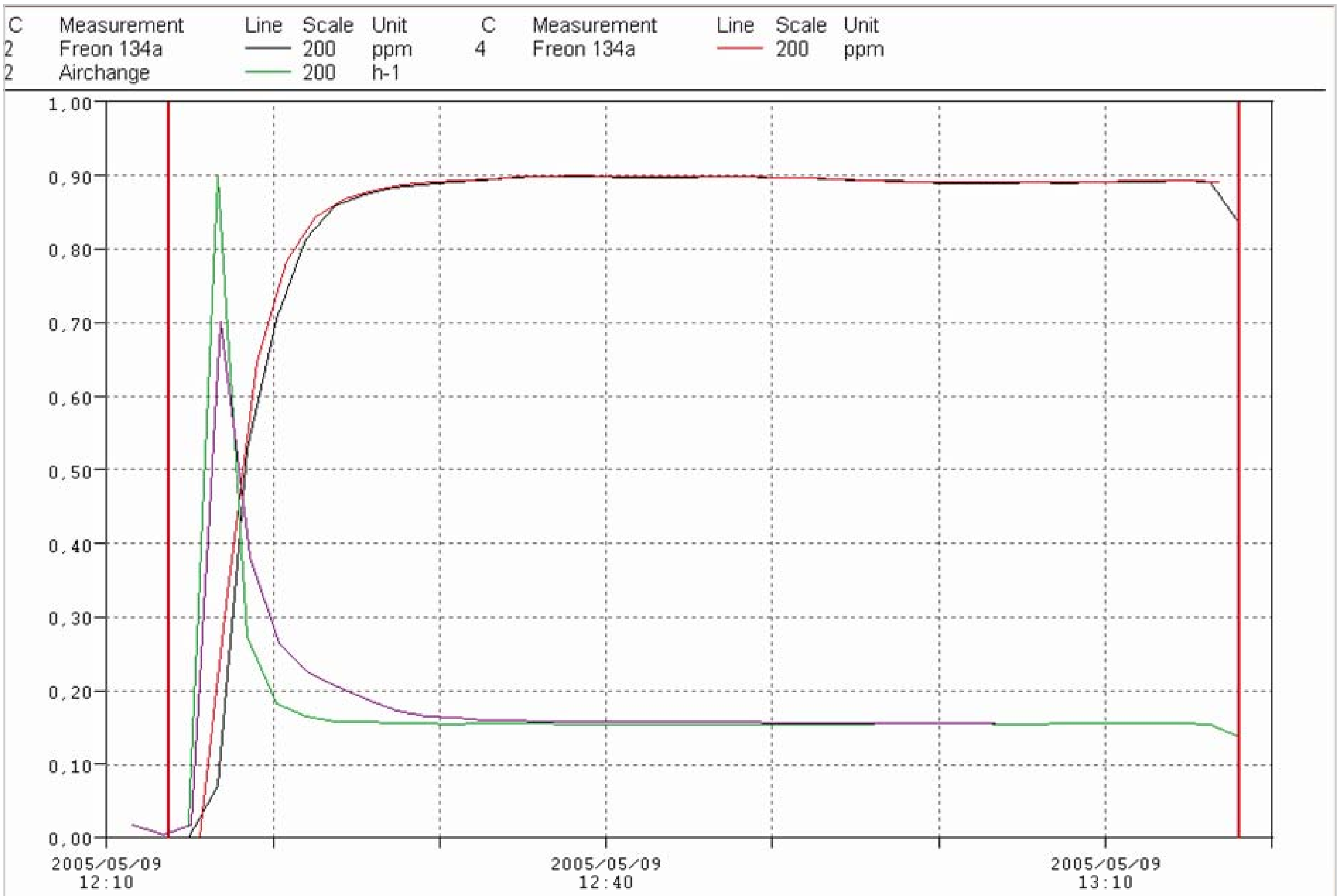

Fig.14. Measurement results from volume flow measurements in a duct with default setting (Purple) and changed setting , Kl=1 and Ta=60, (Green)

The measurements in Fig.15 were done in a duct where it was possible to change the speed of the fan and thus change the volume flow in the duct. It can be seen that the tracer-gas concentration stabilises itself very quickly after a change in fan speed. During the measurements the volume flow in the duct is calculated and after at short stabilisation period the calculated volume flow is very stable. Looking at the tracer-gas concentration one will observe higher fluctuations at higher concentrations, this is due to improper mixing of the tracer-gas with the duct air at low flow rates.

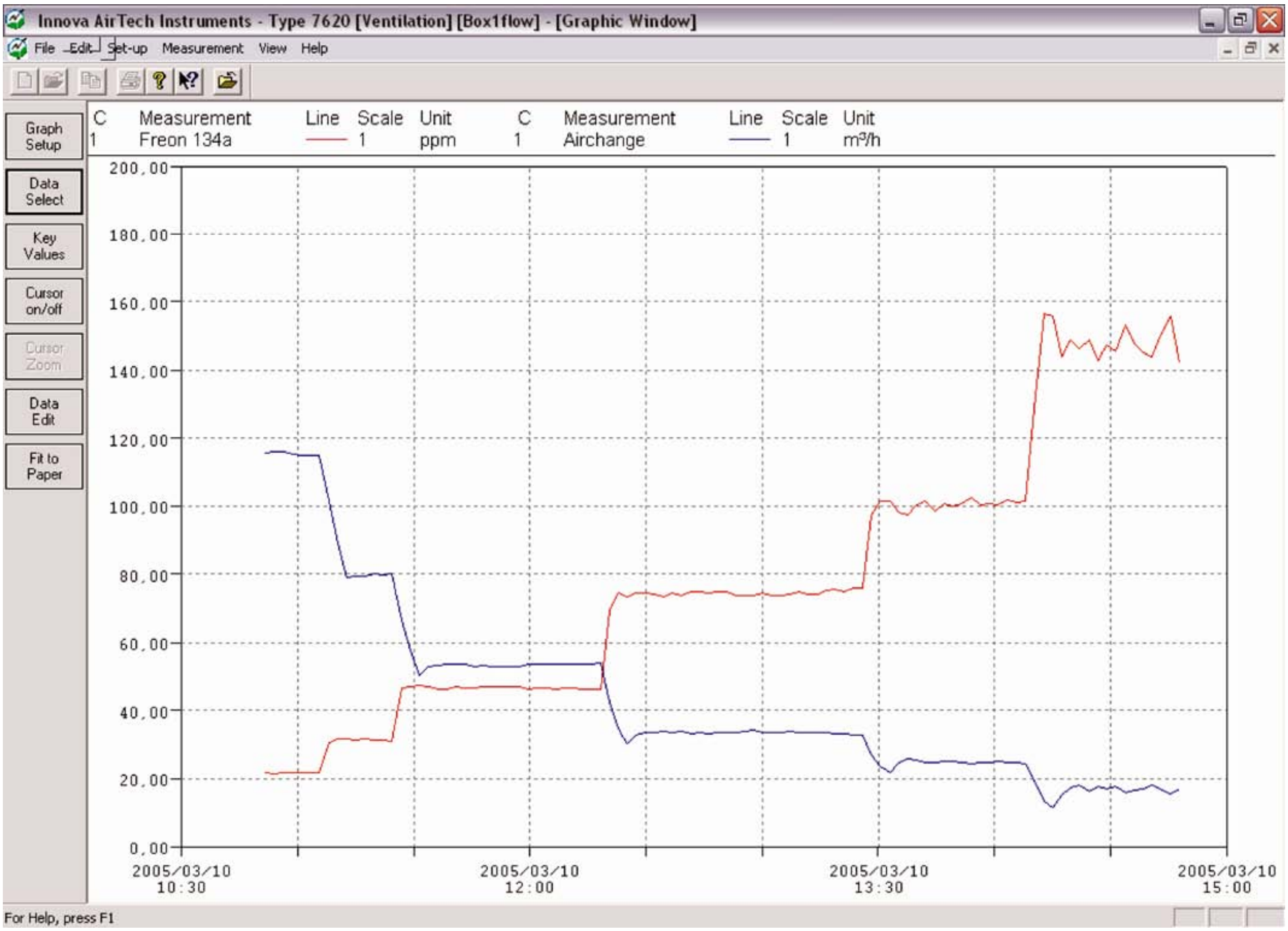

Fig.15 Measurement results from volume flow measurements in a duct with different volume flows.

Comments

The examples used in this Sales Training Note are all from "real life" measurements and gives an indication of how the tracer-gas system and the various techniques can be used. The tracer-gas measurement methods are not only applicable for buildings, offices and family houses but also for vehicles, planes etc. Some times the choice of applicable technique is obvious and the measurements are performed easily and at other times it might not be so obvious or the measurements are giving you a hard time. If none of the hints in this application note seems to solve your problem try and read "7620 Getting Started", which is available for download at www.innova.dk → Software /7620 access.