Implementing the Results of Ventilation Research
16th AIVC Conference, Palm Springs, USA
19-22 September, 1995

Evaluation of an IR-Controlled Ventilation System in an Occupied Office Building

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EVALUATION OF AN IR-CONTROLLED VENTILATION SYSTEM IN AN OCCUPIED OFFICE BUILDING

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SYNOPSIS

The use of IR detectors to steer the ventilation is in principle an attractive approach for optimising the ventilation according to the occupants needs. In order to evaluate the performances under real conditions, one of the BBRI office buildings in Limelette (some 31 offices with in total 51 persons and a variable occupation load) was equipped with a mechanical supply ventilation system in which each terminal is controlled by an IR detector. During a two week period, the performances of the ventilation system were measured in detail (total air flow rate, functioning of each individual terminal, pressure control function, energy consumption, acoustical measurements,...).

The paper presents first the concept of the ventilation system and some of the measured performances at component level. The overall performance of the system is then discussed as well as the impact of the building and ductwork airtightness. Finally conclusions and recommendations for further improvements are given.

1. INTRODUCTION

Ventilation is a major energy consumer in office buildings and it is therefore interesting to control it so as to find a compromise between indoor air quality and energy consumption.

Although research in the recent years has showed that occupants are not the only source of pollution in office building (but also building materials), it is clear that, up to the present, it is the only source upon which a realistic ventilation control can be based.

The use of infrared detectors to steer the ventilation is a possible approach for optimising the ventilation as a function of the occupancy in the ventilated spaces. Other methods like people counting or carbon dioxide measurements can be appropriate as well.

In order to evaluate its performances under real conditions, one of the BBRI office buildings was equipped with a mechanical supply system in which each terminal is controlled by an infrared sensor.

After a description of the investigated system, this paper presents the results of the performed monitoring: evaluations at component level (pressure control, ductwork,...) are first presented, secondly the overall system performances. Then comes a chapter that shows how the ductwork airtightness and the building airtightness impact on the performances of the system. Finally conclusions and recommendations are given.

2. SYSTEM DESCRIPTION

2.1 GENERAL

The studied IR controlled ventilation system is installed in BBRI office building B which is situated in Limelette, 20 km South of Brussels, Belgium. It is a 2-storey office building with a volume of 3000 m^3, counting 31 rooms with 1 to 4 working places each, or 51 working places in total.

The mechanical air supply installation is made of two separated systems, one for each storey. They consists of a constant speed fan, a filter providing the pressure control function (F.A.R. type manufactured by the French firm ALDES), a heating exchanger, ducts and ventilation terminals (OPTO type manufactured by the French firm AERECO).

The system is designed to provide 25 m^3/h of outside air per working place in the rooms that are effectively occupied. When all the rooms are occupied, this provides a total air flow rate of 51 x 25 = 1275 m^3/h for the whole building.

The ventilation system is operating from 6:00 AM to 8:00 PM.

2.2 SUPPLY TERMINALS

The OPTO ventilation terminal is controlled by a motion sensor based upon infrared detection. If presence of occupants is detected in a room, the ventilation is activated thanks to a electro/pneumatic device. When the occupants leave the room, the ventilation remains activated during 15 minutes before switching off.

The terminal can be manually set in four different opening positions corresponding with four different air flow rates: 25, 50, 75 and 100 m^3/h. This setting is made once for all in function of the number of working places in the ventilated space, one working place corresponding with a rate of 25 m^3/h. The pressure in the ductwork should stay between 70 Pa and 130 Pa to ensure a proper operation of the terminals.

2.3 AUTOCONTROLLING FILTER

2.3.1 FILTERING AND PRESSURE CONTROL FUNCTIONS

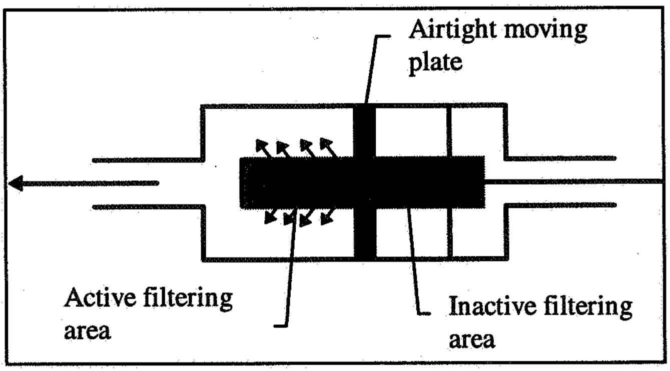

Figure 1 - Pressure control function of the filter

Besides the usual filtering function, this autocontrolling filter is designed to maintain the pressure in the ductwork between certain limits. This control function is of course essential for a ventilation system allowing the total air flow rate to vary with the demand.

The pressure control function is obtained by moving an airtight plate which modifies the active filtering area through which the air is passing (see figure) hence the pressure drop through the filter. The pressure in the ductwork is measured and the position of the moving plate is adjusted in order to keep this pressure between the chosen limits.

Furthermore, this equipment is designed to change automatically the filter when the accumulated particulate matters provoke too high pressure losses in the filter to ensure a normal operation of the ventilation system.

3. MEASUREMENT SET-UP

Various parameters were continuously recorded during the monitoring of the whole system operation: the total supply air flow rates using tracer gas technique, the outside temperature, the temperatures after the pre-heating units, the pressure at the end of the ductwork and just after the fan, the state (open or closed) of each OPTO ventilation terminal of the ground floor system and the position of the airtight moving plate in the autocontrolling filters.

Figure 2 shows the ventilation system with its different components and the positions of the different measurement points.

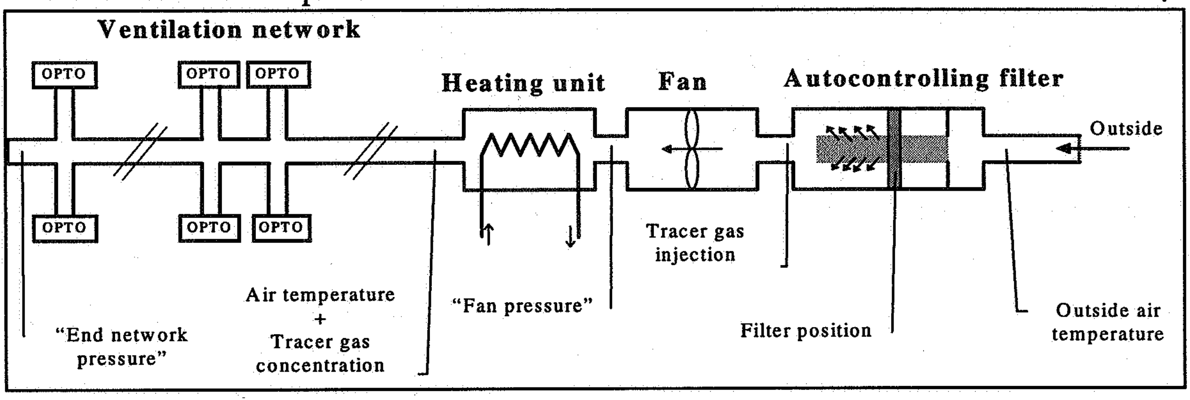

Figure 2 - Monitoring of the whole system operation - Measurement points

Spot measurements of the overall building airtightness, the ductwork airtightness, the acoustical level, the air flow characteristics of terminals and air flow rates at ventilation terminals were also performed.

4. EVALUATION AT COMPONENT LEVEL

4.1 DUCTWORK

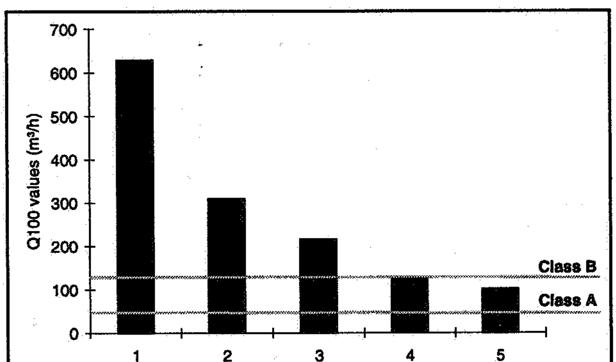

Figure 3 - Ductwork airtightness measurements and EUROVENT 2/2 standard classes

Figure 3 shows the results of the airtightness measurements performed on the ductwork of the first floor ventilation system. They are presented in terms of Q_{100} values, i.e. the air flow rate flowing through the ductwork leakages at a pressure difference of 100 Pa, which is the average pressure of the normal operation range of the ventilation terminals (70-130 Pa).

The EUROVENT 2/2 standard, "Air leakage rate in sheet metal air distribution systems", proposed two classes for ductwork airtightness. The Q_{100} values according to this standard are also shown.

As it can be seen, the initial Q_{100} value was about 630 m³/h which is almost equal to the nominal ventilation air flow rate (625 m³/h). Under these conditions, the system could not operate normally. Several improvements were necessary to reach an acceptable value. The last test (n°5) gave a value slightly better than the class B of the EUROVENT 2/2 standard.

4.2 AUTOCONTROLLING FILTER

The pressure control function should allow in theory to maintain the pressure in the ductwork in the operating range of the ventilation terminal (70-130 Pa)

The following figure gives, for the ground floor, the measured pressures just after the fan and at the end of the ductwork as well as the filter position during a typical day. The maximum filtering area corresponds with the top of the scale (38 cm) and the minimum filter area with the bottom of the scale (0 cm).

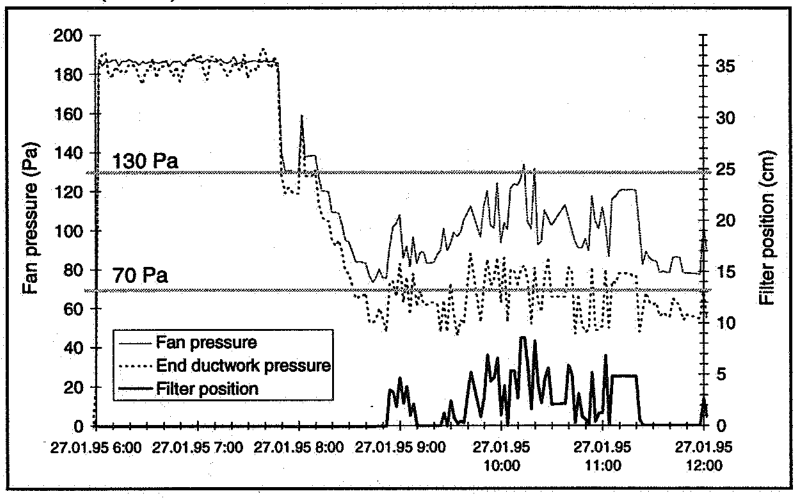

Figure 4 - Filter position, fan pressure and end ductwork pressure (ground floor)

The following remarks can be made:

- In the morning, when the ventilation demand is zero or very low, the filtering area is minimal which should provoke a sufficient pressure drop to decrease the air flow rate through the fan so as to obtain a ductwork pressure between 70 and 130 Pa. However, the measured ductwork pressures are near 180 Pa. This suggests that either the fan is too powerful or the maximal pressure drop the filter can provoke is too small.
- Since the pressure at all ventilation terminals is somewhere between the two measured pressures, it is likely that most of them function within the operating range (70-130 Pa). However, the pressure at the end of the ductwork falls under 70 Pa several times which should be prevented thanks to a better pressure control. Moreover, too low pressures prevent the terminal to close completely and some air can flow into unoccupied rooms.

The following figures show the fan pressure as a function of the filter position and the filter position as a function of the ventilation demand.

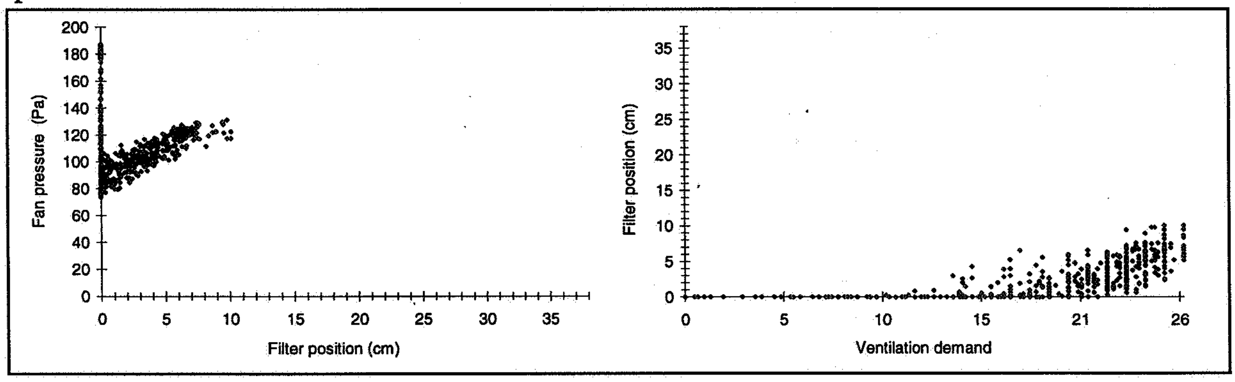

Figure 5 - Operation of the pressure control function of the filter

As it can be seen, the pressure after the fan can vary from 180 Pa to about 75 Pa when the active filtering area is the smallest possible (filter position = 0 cm). One can also observe that the active filtering area of the filter remains quite small (not more than 11 cm over 38 cm).

The pressure control function of the filter operates only when the ventilation demand goes over 10 people. Below this value, the active filtering area is minimal and the pressure varies in function of the air flow rate, it is no more controlled by the filter and, as a consequence, the supplied air flow rate per occupant can strongly vary in the time.

5. OVERALL PERFORMANCES

The overall performance analysis is based on the ground floor measurements (26 places).

The next figure shows the air flow rate effectively supplied to the ground floor in function of the ventilation demand as well as the air flow rate that would be supplied by a perfect system (25 m³/h per person). The air flow rate supplied by a constant air flow rate system installed in the same building, that is 26 x 25 m^3/h, is also shown.

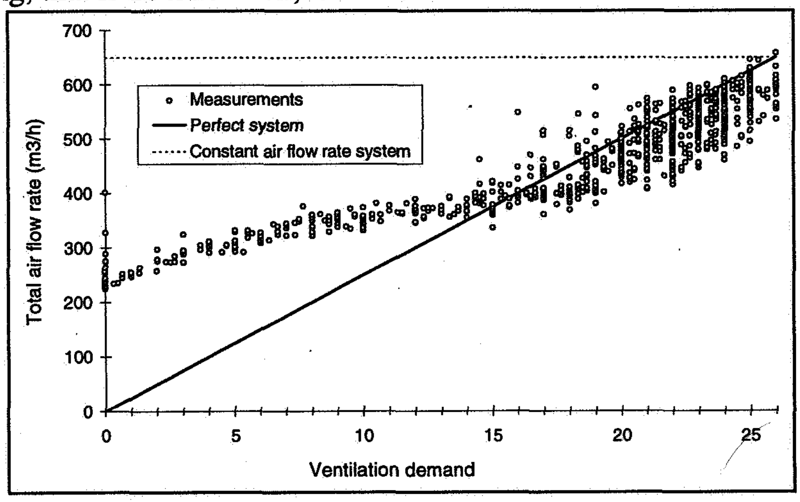

Figure 6 -Air flow rate supplied in function of the ventilation demand - Measurements, perfect controlled system and constant air flow strategy

One can observe that the total air flow rate is quite higher than expected for the low ventilation demand (< 15 people). This is on the one hand due to the bad operation of the pressure control for low demand and, on the other hand, to the ductwork leakages.

It must be stressed that the total air flow rate shown on the previous figure represents the amount of air supplied by the fan and not the amount of air supplied to the occupied rooms. Indeed, a part of the air is supplied through the ductwork leakages to the corridor and another part is supplied through the closed ventilation terminals to the unoccupied rooms.

Briefly put, it can be said that the previous figure gives a correct image of the system performance from the **energy point of view** but does not allow to evaluate the system performance from the **IAQ point of view**.

5.1 SPLIT-UP OF THE TOTAL AIR FLOW RATE

The total air flow rate supplied by the ventilation system (ground floor) is made of three components: the air flow rate supplied to occupied rooms through open terminals; the air flow rate supplied to unoccupied rooms through closed terminals; the air flow rate supplied to the corridor or the basement through ductwork leakages.

On the basis of the air flow characteristics of the ventilation terminals and the ductwork leakages, it has been possible to model the behaviour of the ventilation system and to split the total air flow rate into its different components. This is shown on the next figure as well as the average air flow rate per person in occupied and unoccupied rooms.

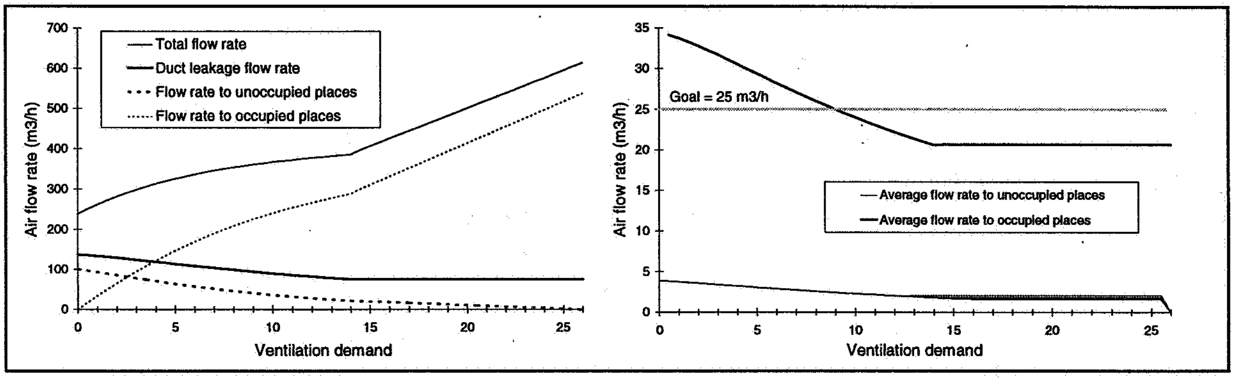

Figure 7 - Split-up of the total air flow rate supplied to the ground floor and average air flow rate per person.

As one can see, the air flow rate through the ductwork leakages varies from 100 m^3/h for the high demand up to 130 m^3/h for the low demand. Moreover, when the ventilation demand is very low, the air flow rate to the unoccupied rooms is about 100^3/h.

The average air flow rate supplied to the people (in occupied rooms) can vary from 34 m^3/h to about 20 m^3/h which is due to the pressure variation in the ductwork owing to the incorrect operation of the pressure control function of the filter.

6. IMPACT OF DUCTWORK AND BUILDING AIRTIGHTNESS

6.1 BUILDING AIRTIGHTNESS

It is clear that the building airtightness plays a very important role in the efficiency of the IR controlled ventilation system. Indeed, the air infiltration results in an additional air flow rate which is totally uncontrolled and thus reduces the saving that can be obtained.

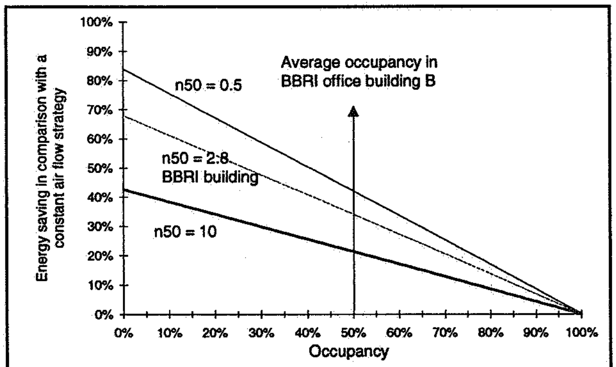

Figure 8 - Energy saving in comparison with a constant air flow strategy for different building airtightness values

The BBRI office building B has an average air infiltration of about 400 m^3/h (simply evaluated from the Q_{50} value) and the ventilation system does not induce any over-pressure in the building which could somehow counteract the air infiltration through the envelope.

The following figure shows the energy savings that can be obtained thanks to an IR controlled ventilation system in comparison with a constant air flow strategy and for 3 degrees of airtightness. It was assumed that the pressure control was perfect (100 Pa).

As it can be seen, the energy saving is about 34% for the present characteristic of building B (n_{50}=2.8 vol./h) for the average measured occupancy (50%). A very good airtightness in such a building would be about 0.5 vol./h which would results in a gain of 42%. A very bad airtightness (n_{50}=10 vol./h) would give a gain of only 21%.

6.2 DUCTWORK AIRTIGHTNESS

The ductwork airtightness is a critical aspect in controlled ventilation systems. We will consider two different cases to illustrate that matter.

First case

It will be assumed that the installed fan has been chosen to provide a maximal air flow rate which takes into account normal ductwork leakages (class B in EUROVENT 2/2 standard) and 25 m^3/h for each working place. The fan is strictly limited to that maximal value.

In this case, if the airtightness of the ductwork is worse than expected, it would result in a too low operating pressure hence air flow rate when the demand is high.

This case is illustrated on the next figures. The first one represents the energy saving that can be achieved in comparison with a constant air flow strategy for two degrees of airtightness.

Normal ductwork leakages (class B in EUROVENT 2/2 standard) are assumed for the constant air flow strategy. The ductwork airtightness of the "leaky ductwork" is taken equal to the first measured value in the BBRI building B, before any improvement and the ductwork airtightness of the "normal ductwork" is taken equal to the last measured value in the BBRI building B, after all the performed improvements.

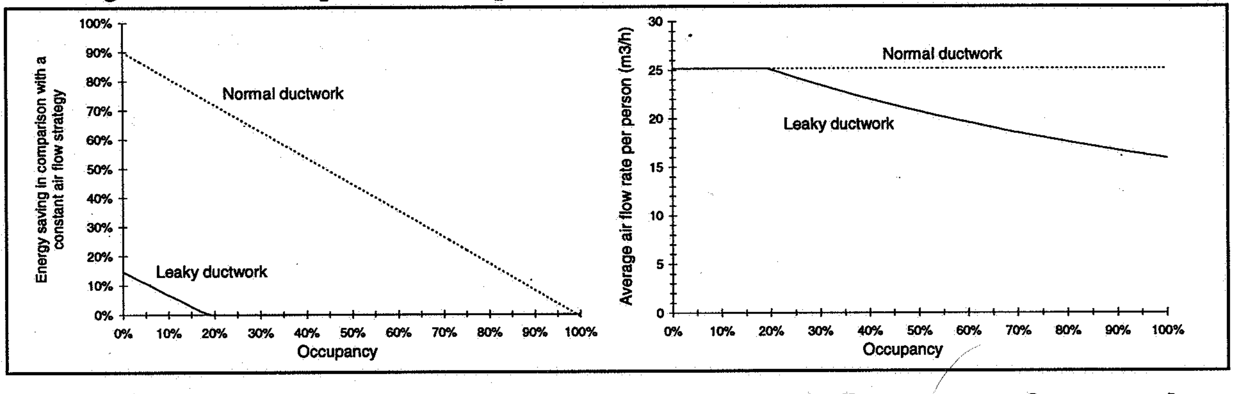

Figure 9 - Energy saving in comparison with a constant air flow strategy for two values of ductwork airtightness - Average air flow rate per person

The impact of the ductwork airtightness is very clear. For the "leaky ductwork", when the occupancy is higher than 20%, the fan gives its maximal air flow rate and every new increase of the occupancy results in decreasing the ductwork pressure and accordingly the air flow rate per person. A lot of air is supplied to the corridor and the basement. Moreover, since the maximal air flow is supplied, the IR control has no impact on the energy consumption. The performance is disastrous from the energy point of view and from the IAQ point of view.

Second case

The chosen fan can supply more than the air flow rate needed. This is a very interesting solution in a building where the number of working places is very likely to change in the time. In this case, if the pressure control operates correctly, the air flow rate supplied in the occupied rooms will be as expected but, due the ductwork leakages, an additional air flow will be supplied to the corridor or the basement which will result in additional thermal losses.

Figure 10 compares the energy saving achieved in comparison with a constant air flow strategy for both values of airtightness.

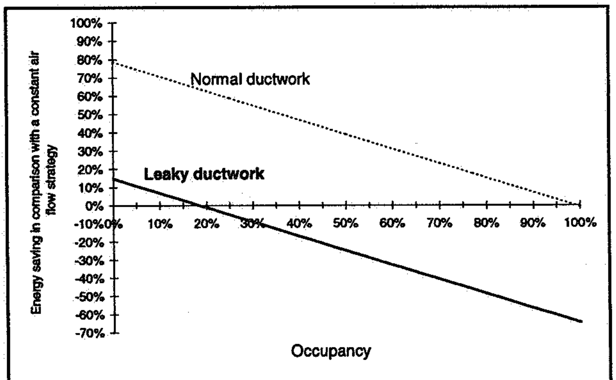

Figure 10 - Energy saving in comparison with a constant air flow strategy for two ductwork airtightness

In this case, the air flow rate per person is as required, i.e. 25 m^3/h, because it is assumed that the pressure control is perfect. However, a large part of the air leaves the ductwork through its leakages which explains why, when compared to the reference case, the energy savings are negative for high occupancy.

7. CONCLUSIONS

The following conclusions can be drawn from the measurements and observations made.

Regarding the performances of the ventilation terminals:

- The detection function of the ventilation terminal works apparently in a satisfactory way.
- Observations showed that under normal conditions, the air velocities in occupied spaces are low enough to avoid draught complaints. Furthermore, the noise levels are acceptable.

Regarding the overall system performances

- The measurements have highlighted the tremendous importance of the duct airtightness. In the investigated building and system, the original airtightness was so poor that the IR control had little impact on the total air flow rate and as a consequence on the energy bill.
- During periods of non-occupation of the building or periods of very low ventilation demand, the noise coming from the ventilation system is not negligible because of the high pressure in the ductwork (up to 180 Pa). A good pressure control should in principle solve this problem.
- A lot of efforts were needed to improve the ducts airtightness so as to come near an acceptable value. It is a very labour intensive activity hence a high cost activity and, therefore, it is clear that the only realistic solution is to achieve a better airtightness from the beginning and clear performance requirements in the technical prescription.
- The pressure variation in the ductwork were considerable (from 60 to 180 Pa). This means that the compromise between indoor air quality and energy consumption is not so optimal. We believe that an improvement is required.

Recommendations

- A special attention should be paid to the ductwork airtightness. We would suggest the following procedure:
    1. clearly specifying a minimum level for duct airtightness in the technical prescriptions.
    2. a systematic testing of the duct airtightness after the installation.
    3. perform improvements if needed.
- The pressure in the duct should be better controlled. We see the following possibilities:
    - a variable fan speed, which is probably a rather expensive solution but it has the advantage that the fan energy bill will drop substantially.
    - a wider operating range for the filters permitting to keep the pressure more or less constant over the complete range of air flow rates.
    - a variable air volume outlet in the non-heated area with a control of the terminal opening position which leads to a constant pressure in the ductwork. This terminal should be placed after the fans but before the pre-heating unit.