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Experimental Study of Exhaust Air Transfer Ratio in a Rotary Heat Recovery Ventilation Unit with Automatic Leakage Control

Lei Fang, Ph.D.

Bjarne W. Olesen, Ph.D.
Fellow ASHRAE

Henning Grønbæk, B.Eng.

Daniel Kampgaard Munck, M.Sc.

ABSTRACT

Air leakage in a rotary heat recovery device in air handling unit (AHU) was studied by a laboratory experiment. The experiment tested a commercial AHU with rotary heat recovery and equipped with various leakage control techniques, e.g. Automatic Leakage Control (ALC^{TM}), rotor speed control (RSC) and purge sector, etc. In the test, exhaust air transfer ratio (EATR) of the AHU was measured by tracer gas method at two levels of airflow rates in both constant airflow and constant pressure operation modes of the test AHU. The results showed that EATR of the test AHU could be as high as 16% without proper leakage control. The ALC and RSC effectively prevents pollutant transfer from the rotor during both static and dynamic operation of the AHU. The maximum EATR measured from this test was 0.27% when ALC, RSC and purge sector were applied simultaneously for leakage control.

INTRODUCTION

Most of air handling units in Scandinavian countries are equipped with heat recovery devices. Heat recovery devices greatly decrease the energy consumption for ventilation of buildings. Among different types of heat recovery devices, rotary heat exchanger is one of the commonly used devices due to its high effectiveness of heat recovery, compactness, long lifetime, no condensation drain required and frost resistant at very low outdoor air temperature. The major concern of using the rotary heat exchangers is air leakages between the supply and extract air streams. The leakage is mainly due to bypass at the interface between the supply and extract air streams at the heat exchanger boundary, and due to the carryover of air at the separation point between the two air streams when the rotor passes from one air stream to the other during its normal rotation.

Han and Kim (2005) studied the air leakage and heat transfer characteristics of a commercially available rotary-type air-to-air heat exchanger with a fiber polyester matrix. Crossover leakage between the exhaust and supply air is measured using a tracer gas method for various ventilation rates and rotational speeds of the rotor. They found that the leakage ratio increased with the increasing of rotor speed, but decreased with the increasing of airflow rate. At 42 m3/h, the maximum leakage ratio went up to 50%. They found further that the leakage due to bypass was a function of airflow rate only, and the leakage due to carryover was a function of rotor speed only. Similar results were also observed by an earlier study conducted by Shoukri and D'Silva (1978). Usually, the leakage due to bypass can be reduced by brush seals, and the carryover is usually reduced by a

Lei Fang is an associate professor in the Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark. **Bjarne W. Oleson** is a professor in the Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark. **Henning Grønbæk** is a product expert in Exhausto A/S, Langeskov, Denmark. **Daniel Kampgaard Munck** is a product manager in Exhausto A/S, Langeskov, Denmark.

small purge sector arranged in the rotor and using the supply air stream to blow this sector before the rotor rotates from the extract to the supply air streams. With these measures, the total leakage can be greatly reduced but there could still be a significant leakage if the pressure of supply air channel is not higher than that in the extract air channel (Shang et al. 2001). These studies indicated that a proper control of both pressure between supply and exhaust air channels and the speed of rotor are essential for reducing air leakages when using rotary heat exchangers in air handling units to avoid pollutant transfer from the exhaust to supply air streams. This study tested the performance of a commercial air Handling unit equipped with automatic leakage control (ALC), rotor speed control (RSC) and a purge sector in the rotor.

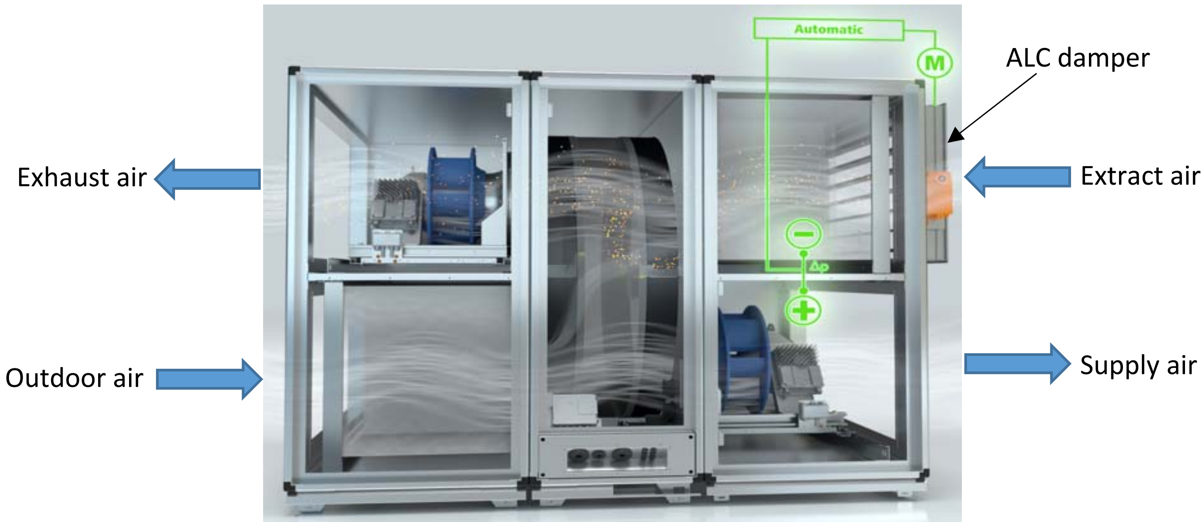


Figure 1 The test unit equipped with ALC and RSC.

METHODS

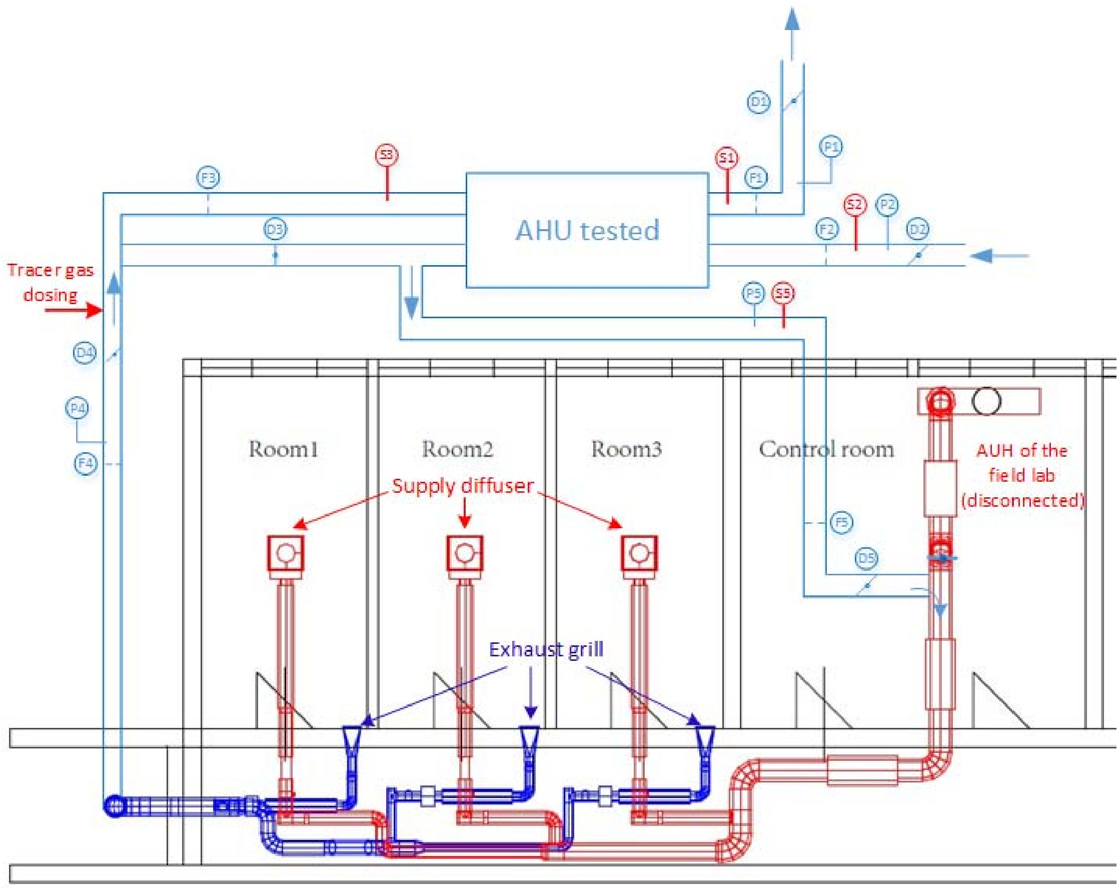
The test unit

The AHU tested was a rotary heat recovery unit as shown in Figure 1. The AHU equipped with ALC, RSC and a purge sector in the rotor to prevent leakage from extract to supply air stream. ALC system measures the pressure difference between supply and extract air channels and automatically regulates the opening of a damper installed at the extract inlet of the AHU to maintain overpressure on the supply side of the air channel to avoid leakage of the extract air into the supply air stream. RSC system automatically regulates the rotation speed of the rotor according to the airflow rate. Together with the purge sector of the rotor, leakage due to carryover can be avoided by RSC.

Setup of the test facility

The test experiment was carried out in a field lab for indoor climate research. A test AHU was connected to the field lab that has three rooms (each has 18 m^2). Figure 2 shows the connection of test AHU in the field lab. The test used the supply and exhaust air channels of the field lab but the AHU of the field lab was disconnected and replaced by the test AHU. Each room in the field lab has a damper in both supply and exhaust air channels that can be controlled independently. Airflow transducers, pressure transducers, tracer gas dosing and sampling tubes and manual dampers were installed at each of the four inlet and outlet of the test AHU. Figure 2. Shows the locations of air sampling, transducers and dampers mounted.

The test AHU was placed in the garden outside the field lab. It took the supply air from the garden and rejected the exhaust air outside the garden that was surrounded by buildings.



Ⓟ : pressure transducer, Ⓕ : airflow rate transducer, Ⓓ : air damper (manual), Ⓢ : air sampling for tracer gas measurement.

Figure 2 Experimental setup and the locations of tracer gas dosing and sampling, airflow and pressure measurements.

Measurement and calculation of exhaust air transfer ratio (EATR)

The test follows the procedure of carry-over test described by European Standard EN 308 (1997). However, the procedure used in this test measured the total leakages of the test AHU including both carry-over and other leakages due to pressure difference between supply and exhaust in the test AHU.

The EATR was measured by dosing tracer gas R134a at the inlet of the extract side of the test AHU and measure the concentration at the inlet and outlet of the supply side of the AHU. The EATR was then calculated as follows.

$$EATR = \frac{(Cs - Co)}{Cs} \cdot 100\% \quad (1)$$

Where:

EATR is the ratio of total leakage (%) representing the percentage of the air pollutants transferred from exhaust side to supply side of the test AHU due to both carry-over and other leakages of the unit tested.

Cs is the concentration of tracer gas (ppm) measured at the outlet of supply side of the test AHU

Co is the concentration of tracer gas (ppm) measured at the inlet of supply side of the test AHU (i.e. concentration of the tracer gas in outdoor air)

Ce is the concentration of tracer gas (ppm) measured at the inlet of extract side of the test AHU

The dosing rate of the tracer gas was controlled at 5 ml/s by a mass flow controller. With this dosing rate, the concentration of tracer gas at the extract inlet of the test AHU was between 15 ppm to 75 ppm depending on the airflow rates tested.

The concentration of the tracer gas was measured by a six-channel photoacoustic gas analyzer with the detection limit of R134a < 0.01 ppm and repeatability ±1% of the measured value.

Table 1. Different operation modes and the control functions tested

			ALC on		ALC off			
			RSC on	RSC off	RSC on		RSC off	
					With MTD	Without MTD	With MTD	Without MTD
With purge	Constant airflow	Low airflow	X		X		X	X
		High airflow	X		X		X	X
	Constant pressure	Low P, low F	X		X		X	X
		Low P, high F	X		X		X	X
		High P, low F	X		X		X	X
		High P, high F	X		X		X	X
Without purge	Constant airflow	Low airflow						X
		High airflow						X
	Constant pressure	Low P, low F						X
		Low p, high F						X
		High P, low F						X
		High P, high F						X

Note: In the test, the MTD was applied by setting a fixed opening of the ALC damper to establish +20 Pa pressure at supply air channel over the extract air channel at a high level of airflow rate.

Test conditions

The tests were conducted at two operation modes of the test AHU – constant airflow mode and constant pressure mode each at two levels airflow rate and/or pressure. For constant airflow mode, the test AHU was tested at low airflow rate of 600m^3/h and high airflow rate of 1200 m^3/h. For constant pressure mode, the test AHU was tested at low pressure of 55 Pa and high pressure of 300 Pa (measured at P5 shown in Figure 2).

At each operation mode, the tests were conducted with and without different leakage control measures, i.e. with and without ALC, RSC, purge or manual trim damper (MTD). The EATR at different operation modes and the control functions tested are listed in Table 1.

Test procedures

Test of the AHU at constant airflow operation mode. For the constant airflow operation mode, the test AHU was started at low levels of airflow rate of 600m^3/h. When the airflow rate reached to the steady state 600 m^3/h, dosing of tracer gas started and the dosing was kept continuously at the constant level of 5 ml/s until the end of the test on that day. At least 6 air samples were made, and the average concentrations of the tracer gas was used for calculating EATR of the AHU tested using eq. (1). After more than 6 samples of the tracer gas were made, the airflow rate of the test unit was increased to 1200 m^3/h and the air samples were made after the airflow rate reached to the steady state value again. At the end, the airflow rate in the test unit decreased back to 600 m^3/h.

Test of the unit at constant pressure operation mode. For the constant pressure operation mode, the tests were conducted at two levels of airflows with both low and high pressure in the system to simulate a VAV system. The total airflow rates were adjusted by opening and closing the dampers connected to room 1 and room 2. The high airflow conditions were achieved by opening dampers in all three rooms and the low airflow conditions were achieved by fully closing the damper connected to room 1 and 50% closing the dampers connected to room 2. The dampers in room 3 remained open all the time during the test.

The test for the constant pressure operation mode started from the low pressure and high airflow rate condition, i.e. run the AHU to provide 55Pa of air pressure in the ventilation system and keep all dampers in the three test rooms opened. When the pressure of the system reached steady state, tracer gas dosing was started. After at least 6 samples, the dampers connected to rooms 1 and 2 were closed to 100% and 50% respective. The next condition was to open the closed dampers back to 100% followed by the same sampling procedure. After the test at low pressure level, the test was continued by switching the pressure in the ventilation system to high pressure of 300 Pa; The same procedure of changing the airflow rate by opening and closing the dampers in room 1 and 2 was repeated and the air samplings were made at each condition when pressure in the system reached steady states.

The above test procedures for both constant airflow and constant pressure operation mode were repeated at different conditions with different leakage control measures applied as shown in table 1.

RESULTS

The results of EATR calculated using the data obtained from the test are summarized in table 2.

The results of this test showed that the AHU with rotary heat recovery device could transfer up to 16% of pollutants from exhaust side to supply side provided that the AHU operates without any control to avoid such pollutant transfer.

With purge sector but without any other controls, the EATR could be up to 9.6%.

With purge sector and MTD, the EATR could be up to 8.9%.

With purge sector and MTD and RSC, the EATR could be very much reduced to a max of 1.9%.

With purge sector and ALC and RSC can achieve a minimum transfer of pollutant with a measured EATR lower than 0.27%.

Table 2. The measured EATR at different operating modes with the selected leakage control functions

			ALC on		ALC off			
			RSC on	RSC off	RSC on		RSC off	
					With MTD	Without MTD	With MTD	Without MTD
With purge	Constant airflow	Low airflow	0.11%		1.9%		7.5%	7.8%
		High airflow	0.27%		0.37%		0.91%	1.7%
	Constant pressure	Low P, low F	0.14%		0.55%		8.9%	9.6%
		Low P, high F	0.16%		1.5%		7.4%	9.1%
		High P, low F	0.20%		0.14%		0.26%	0.30%
		High P, high F	0.27%		0.43%		0.52%	3.0%
Without purge	Constant airflow	Low airflow						8.7%
		High airflow						4.5%
	Constant pressure	Low P, low F						16%
		Low p, high F						11%
		High P, low F						5.1%
		High P, high F						4.5%

DISCUSSIONS

The results of this test found that the test AHU had very small transfer of tracer gas from the exhaust side to supply side when purge, ALC and RSC measures were applied simultaneously. The EATR measured was very low at both constant airflow and constant pressure operation modes when the unit was running at both high and low airflow rates. The main reason was that the ALC could guarantee a positive pressure drop from supply side to the exhaust side of the AHU tested. This was confirmed by the measurement of ΔP between supply and exhaust side of the unit. Figure 3 and 4 shows the ΔP measured in both constant airflow and constant pressure operation modes during steady state operation and transient periods from one condition of operation to another. Only in one transient period (when airflow rate was adjusted from low level to high level at high pressure operation mode) observed negative pressure in few seconds between supply and exhaust (figure 4). This was mainly due to the overshoot of the regulation. However, the ΔP quickly converged to a positive steady state pressure with no increased tracer gas transfer from exhaust to supply was measured.

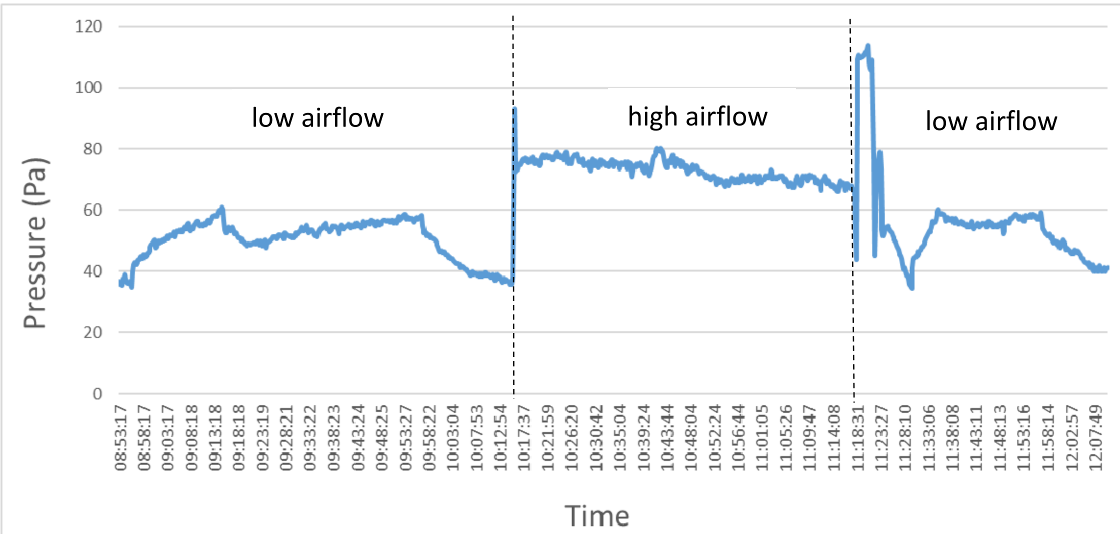


Figure 3 The differential pressure between supply and exhaust side of the unit recorded during the experiment when the test unit operated at constant airflow mode with purge and ALC.

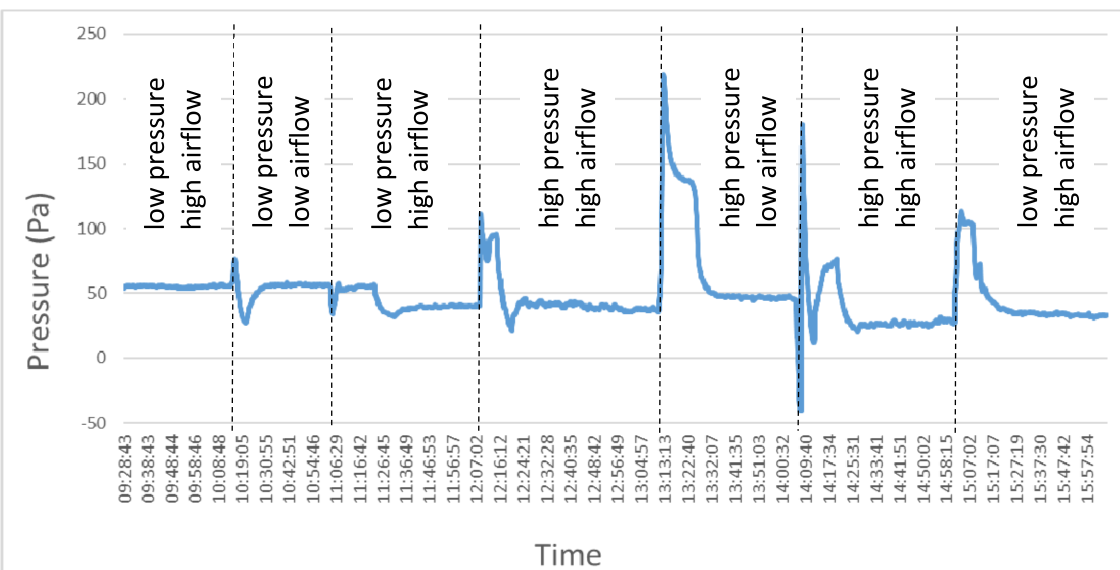


Figure 4 The differential pressure between supply and exhaust side of the unit recorded during the experiment when the test unit operated at constant pressure mode with purge and ALC.

A very small but detectable transfer ratios of tracer gas from exhaust to supply side of the unit were detected when purge, ALC and RSC were applied. The same phenomenon was found in the study of Shang et al (2001). They pointed out that the purge sector cannot totally eliminate carryover due to the laminar airflow in the small wheel pores. This could be the explanation for the small EATR detected in our experiment. Due to the small pores in the rotor, the airflow pattern inside each pore must be laminar which led to a very low speed of the air movement along the surface of pores. Since the cross profiles of the pores are usually triangles the air speed at the each angles of the pore profiles would be even lower which led to the removal of the tracer gas in the angles of the pore profiles very inefficient by the purge airflow especially when the area of the purge sector was very limited. The very small EATE detected could be negligible for the transfer of gas phase chemical pollutants. For particles in general and especially for airborne pathogenic particles, their behavior of carryover in the rotor could be different from that of molecules of tracer gas. Considering that the AHUs are usually protected by particle filters, the carryover of particles on the rotor may not be an issue of pathogen transfer. However, it remains to be investigated further.

CONCLUSIONS

The test showed that the Air Leakage Control and Rotor Speed Control techniques together with purge sector are very effective to avoid pollutant transfer from exhaust side to supply side of an AHU equipped with a rotary heat recovery device. The Leakage Control and Rotor Speed Control effectively prevent pollutant transfer from the rotor during both static and dynamic operation of the AHU in either constant airflow or constant pressure mode of operation. The maximum exhaust air transfer ratio measured from this test was 0.27% when Air Leakage Control, Rotor Speed Control and purge sector were applied simultaneously for leakage control.

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