# Analysis of Internal Leakages of Residential Ventilation Units by various test methods

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**Abstract.** Internal leakages of bidirectional residential ventilation units (RVU) have a negative impact on hygiene and energy efficiency. Therefore, internal leakages are an essential part of the European standards and should be a requirement and part of the energy labelling in the revision of Regulation EU 1253/2014. The current test standard defines a static pressure method intended for RVUs with plate heat exchangers. In addition, there is an in-duct method and a chamber method, using tracer gas, for air handling units (AHU) with rotary heat exchangers. The Eurovent Product Group Residential Air Handling Units launched a project to analyse these methods. The project was also supported by the Swiss Federal Office of Energy and GebäudeKlima Schweiz. Two AHUs, one with plate heat exchangers and the other with rotary heat exchanger, were tested with all three methods. The finding was that the results of the different methods were not comparable. A Master's study confirmed this with a third RVU. Hence, a new method was introduced, the so-called Advanced Pressure Method (APM). This approach allows testing without tracer gas, but with comparable results to the in-duct method. The APM is based on a node model of the flow paths within the RVU. All in all, the APM is a reliable approach to determine the internal leakage, even though the measurement uncertainty is higher than with the in-duct method. The accuracy is limited due to the sensitivity of the mathematical model. Therefore, the APM has been proposed for the use of the APM in manufacturers' laboratories. Furthermore, in the EN 13142 standard, the internal leakage is used to correct the temperature efficiency. The current test standard leads to results that depend not only on the quality of an RVU, but also on the test method. In addition, test conditions that are not clearly defined, e.g. rotary speed, have an effect. The project is intended to open the discussion on the three mentioned test standards and their influence on energy labelling.

**Keywords.** Residential Ventilation Unit, Leakage, Test Method, Tracer gas measurement.
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## 1. Introduction

Before a bidirectional Residential Ventilation Unit (RVU) hits the market, it will get tested not only for the temperature efficiency, but also for its external and internal leakage. These are mandatory product information according to the European ecodesign requirements [1]. The testing standard for ducted bidirectional RVUs EN 13141-7:2021 [2] defines three different test methods for the determination of internal leakages of RVUs, but it is a common understanding among experts that, with the current knowledge, the results cannot be directly compared or converted. The resulting leakage will be considered to calculate the corrected temperature ratio. The leakage rates vary within the different methods and thus some exchangers get rated better or worse than others. In general, the higher the internal and external leakage of the unit, the lower the efficiency of it. This is taken into account when correcting the temperature ratio with Table 2 in standard EN 13142:2021 [3].

Against this background, the Eurovent Product Group Residential Ventilation Units (PG RAHU) has launched a project to compare existing test methods for internal leakage of ducted bidirectional RVUs. The first target was to sort out the existing test methods and investigate if there is any relation between them. Next, try to work out a base for a unified test method for all types of exchangers. This could open the possibility for developing a common and standardized test method for RVUs with all categories of heat recovery [4].

## 2. Object and method

First, two standard RVUs were measured using the three existing test methods to get results that can be compared.

### *2.1 Existing standard test methods*

In the European standard EN 13141-7:2021, Annex B.2 and Annex C.3, three different methods for the determination of the internal leakage of ducted bidirectional RVUs are defined [2].

**Pressure method** (see **Fig. 1**): Adjustable fans are connected on each side of the unit, but the unit itself is switched off. The fan connected to the supply air side is used to set a pressure difference of 0 Pa towards the ambient pressure. The fan on the exhaust air side can then be used to vary the over or under pressure on the exhaust air side. In addition, a gas meter or volumetric flow meter is installed on the supply air side, to measure the air flowing from the side set to over pressure or under pressure to the one set zero to ambient. The measured air volume flow is then set in relation to the reference air volume flow and thus results in the leakage rate. According to EN 13141-7:2021 the pressure method applies for plate heat exchangers.

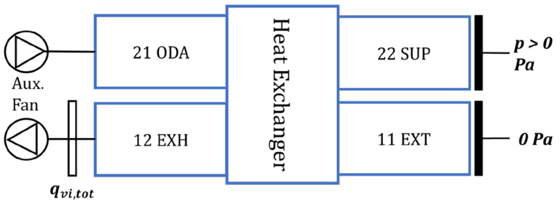



**Fig. 1 –** Test setup for Pressure Method

**In-duct method** (see **Fig. 2**): The In-duct method applies to Rotary RVU when it is known that the external leakage of the unit is not higher than three percent. The unit is connected to all four air ducts and runs on reference conditions described in the standard EN 13141-7:2021. The tracer gas itself is introduced into the extract air. The concentration in all four duct connections is measured. The transfer ratio $\boldsymbol{R_s}$ of recirculated air in the supply air stream is calculated with equation (1):

$$\boldsymbol{R_s} = \frac{c_{22} - c_{21}}{c_{11} - c_{21}} \quad (1)$$

where $\boldsymbol{c_{11}}$ is the tracer gas concentration in the extract air, $\boldsymbol{c_{21}}$ in the outdoor air and $\boldsymbol{c_{22}}$ in the supply air. The transfer ratio of recirculated air in the exhaust air stream is calculated analogously.

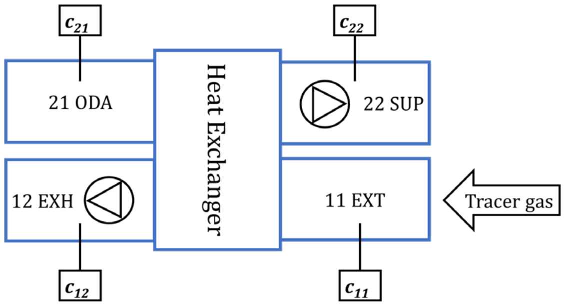



**Fig. 2 –** Test setup for In-duct Method

**Chamber method** (see **Fig. 3**)**:** In the Chamber method the RVU is placed in a chamber, where a high dosage of tracer gas is dispensed. The tracer gas is mixed well with the air. The connections of outdoor air and supply air are led into a low concentrated chamber, while the exhaust and extract air connections end open into the high-dosage chamber. The unit will be running at reference conditions, too. Since, with the Chamber method, the sum of the internal transfer and external transfer are determined, the result is defined in EN 13141-7:2021 as: $\boldsymbol{R_{s,tot}}$ total transfer ratio in supply air.

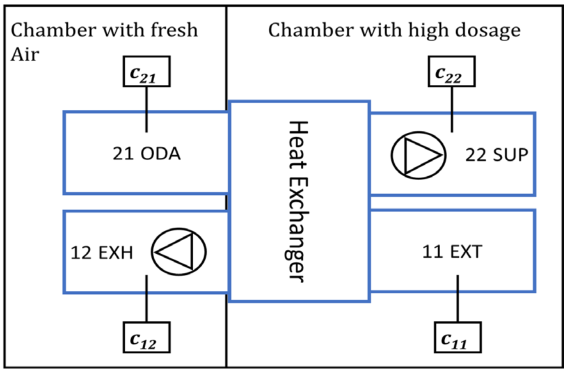



**Fig. 3 –** Test setup for Chamber Method

### *2.2 Test Procedure*

Two ducted bidirectional RVUs have been delivered by the PG RAHU to the HVAC testing laboratory of the Hochschule Luzern (HSLU):

- a RVU with a **rotary heat exchanger** (in the following called Rotary RVU) and

- a RVU with a counterflow **plate heat exchanger** (in the following called Plate RVU)

The maximum flow rate of the RVUs is 400 m³/h (± 6 %) and the reference flow rate is 280 m³/h (± 6 %). The configuration of the RVUs include both fans (supply and exhaust) located downstream the heat exchanger. Both units, regardless of the heat exchanger category, have been tested by all three test methods for internal leakage of EN 13141-7:2021:

- Internal leakage with pressure method (**Pressure method**)

- Internal leakage with tracer gas with in-duct method (**In-duct method**)

- Total leakage with tracer gas with chamber method (**Chamber method**). In the project the concentration was measured in all four ducts as well as in each chamber.

Before the internal leakage tests, the external leakage was measured with static over and under pressure according to EN 13141-7:2014, Annex B.1 (in the following called external leakage test). The intention of the external leakage test was to confirm the external tightness of the units. During the In-duct method and the Chamber method the internal leakage of the Rotary RVU was measured with different rotor speed (0, 4, 8 and 12 rpm) to determine the carryover leakage and the pressure leakage separately. Both RVUs have been equipped with additional tabs for pressure measurement to acquire additional information about the pressure ratios and distribution during the leakage tests and in regular operational conditions.

# 3. Results of the test methods

## *3.1 Leakage rates and classification*

**Tab. 1** summarizes the different test results. Detailed test results can be found in the test reports of the Rotary RVU [5] and Plate RVU [6]. The results of the Rotary RVU are shown by the different settings of the rotor speed.

**Tab. 1 –** Results of the leakage tests according to EN 13141-7:2021 of the measured RVUs.

| | Ext. leakage | Int. leakage | Total leakage | Int. leakage |
|---|---|---|---|---|
| | | Pressure | Chamber | In-duct |
| Plate RVU | 1.0 % | 1.8% | 1.1 % | 0.6 % |
| Rotary RVU 0 rpm | 0.6 % | 3.4 % | 1.7 % | 0.9 % |
| Rotary RVU 4 rpm | 0.6 % | n.a. | 2.9 % | 2.1 % |
| Rotary RVU 8 rpm | 0.6 % | 3.8 % | 4.1 % | 3.3 % |
| Rotary RVU 12 rpm | 0.6 % | n.a. | 5.4 % | 4.6 % |

Accordingly, for the measured leakages the classification of the units according to EN 13141-7:2021 are shown in **Tab. 2**.

**Tab. 2 –** Leakage classification of the measured RVUs.

| | Pressure | Chamber | In-duct |
|---|---|---|---|
| Plate RVU | Class A1 | Class B2 | Class C2 |
| Rotary RVU 0 rpm | Class A2 | Class B2 | Class C2 |
| Rotary RVU 4 rpm | n.a. | Class B3 | Class C3 |
| Rotary RVU 8 rpm | Class A2 | Class B3 | Class C3 |
| Rotary RVU 12 rpm | n.a. | Class B3 | Not classified |

The leakage at the speed of 4 rpm and 12 rpm with the pressure method couldn`t be measured since the programmed speed control wasn't available at the time.

## *3.2 Conclusions on the standard methods*

Overall, the tested RVUs were very tight and the measured leakages of the two units comply well with the product information of the manufacturers. The classification and leakage ratios for each of the two units with the different methods could not be compared or converted.

The internal leakage of the Rotary RVU depends not only on the tightness of the casing and sealing, but also on the rotor speed. The final report of the project [7] shows the dependency of the internal leakage on the rotor speed, determined with the In-duct method and the Chamber method. Roughly estimated, the In-duct leakage is the subtraction of the external leakage from the chamber leakage. For the exhaust air leakage it is reversed, the in-duct leakage is the sum of external leakage and chamber leakage. Accordingly, the total leakage consists of the leakage caused by constant pressure, which can be determined in the static state of the rotor, and the leakage caused by the carry over.

For the examined RVUs, the values of the internal leakage are lower with the In-duct method than for the Pressure method. This can't be seen as a general conclusion. The test results and the assertion can be different for other constructions, fan positions, components (e. g. pressure loss) and position of the leaks. Further work and analyses are necessary for a differentiated statement. Nevertheless, the result shows that the pressure method is pointing in the right direction. Furthermore, interesting results of these comparison tests were the additional pressure measurements for the pressure distribution inside the RVUs. This additional information seems a promising option to refine the pressure method, which is dealt in the next chapter.

# 4. Advanced Pressure Method

The Advanced Pressure Method (APM) is a proposal to obtain all the relevant information for the calculation of the internal leakage without tracer gas. The RVU model used for this is shown in **Fig. 4**.

## *4.1 Model*

The APM is based on a node-resistance model of the RVU, analogously to an electrical network.

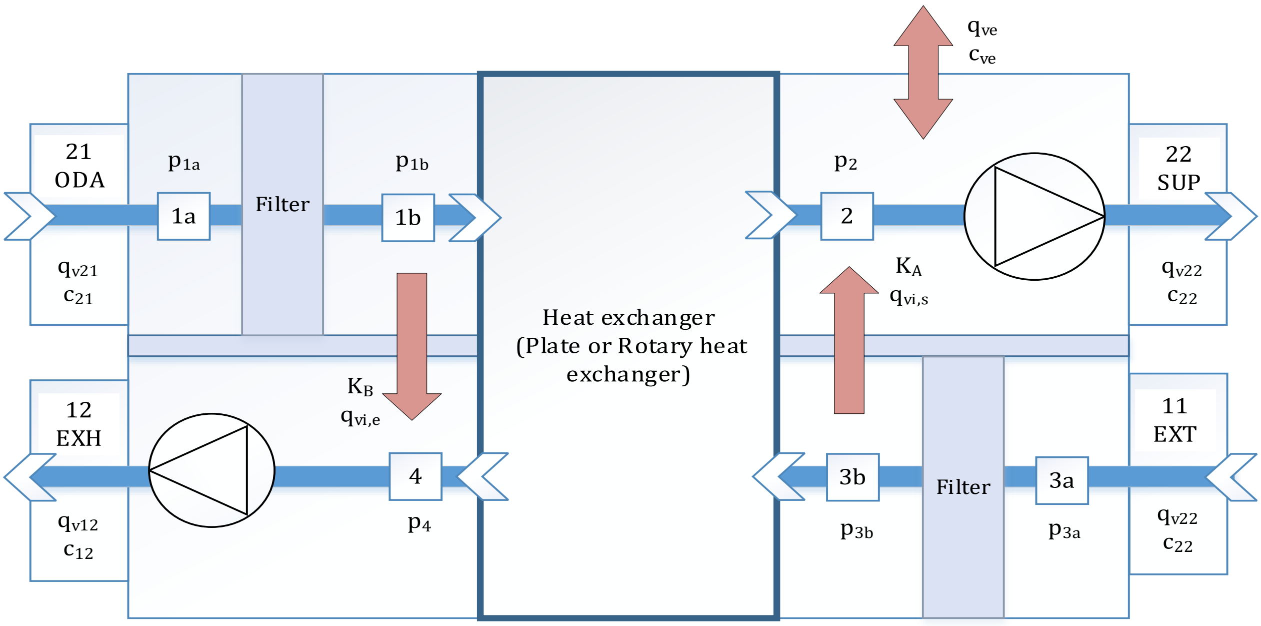



**Fig. 4 –** RVU model used for the APM

Physically correct would be a model with power functions to describe the relationship between the pressure difference and the air flow rate between the nodes. The comparison of the numerical tests with linear and power functions showed no significant difference in the results. Therefore, to keep the model simple and easier to understand at this stage, it was decided to use linear simplification.

It is assumed that the relevant internal leakages occur between the points 1b – 4 and 3b – 2 shown in **Fig. 1**. **Tab. 3** explains the symbols used to picture the APM.

**Tab. 3 –** Symbols for APM.

| Symbol | Unit | Designation |
|---|---|---|
| $p$ | Pa | Pressure |
| $c$ | ppm | Tracer gas concentration |
| $q_v$ | m³/h | Air volume flow |
| $K$ | Pa/(m³/h) | Resistance |

In addition, the indices for the symbols used with the APM are listed below in **Tab. 4**.

**Tab. 4 –** Indices for the APM.

| Index | Designation |
|---|---|
| **11/EXT** | Extract air at the duct connection of the RVU |
| **12/EXH** | Exhaust air at the duct connection of the RVU |
| **21/ODA** | Outdoor air at the duct connection of the RVU |
| **22/SUP** | Supply air at the duct connection of the RVU |
| **1a ,1b ,2** | Nodes of pressure tabs on supply air side |
| **3a, 3b, 4** | Nodes of pressure tabs on exhaust air side |
| **A** | Relating to the leak between nodes 3b – 2 |
| **B** | Relating to the leak between nodes 1b – 4 |
| **e** | Exhaust air side, or external |
| **i** | internal |
| **int** | Relating to internal leakage |
| **s** | Supply air side |

The flow resistances in these paths are called $\boldsymbol{K_A}$ for the supply air side and $\boldsymbol{K_B}$ for the exhaust air side. The reciprocal value of $\boldsymbol{K_A}$ is the leakage coefficient $\boldsymbol{C_A}$ and the reciprocal value of $\boldsymbol{K_B}$ is the leakage coefficient $\boldsymbol{C_B}$. The complex model of the RVU in **Fig. 1** is abstracted and reduced to the elements that are necessary for the calculation, see **Fig. 5**.

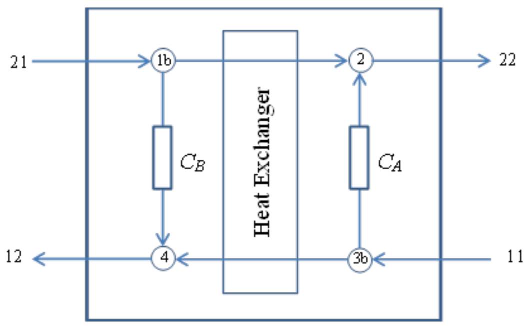



**Fig. 5 –** Abstracted model of the APM

For testing purposes one of the duct connections is sealed. At the second duct connection on the same main air path (either 11 – 12 or 21 – 22) the total of the internal leakage flow rate $\boldsymbol{q_{vi,tot}}$ through the leakage paths $\boldsymbol{C_A}$ and $\boldsymbol{C_B}$ is measured. The values of $\boldsymbol{C_A}$ and $\boldsymbol{C_B}$ are unknown and thus have to be determined with two equations, which represent two independent measurements.

Values from measurement series No. 1 are from here on marked with index 1 and those from measurement series No. 2 with index 2. These indices are listed after the indices of Table 4. With two measurements, equations for $q_{vi,tot1}$ and $q_{vi,tot2}$ are built up with equation (2) and (3).

$$q_{vi,tot1} = \Delta p_{A1} \cdot C_A + \Delta p_{B1} \cdot C_B \quad (2)$$

$$q_{vi,tot2} = \Delta p_{A2} \cdot C_A + \Delta p_{B2} \cdot C_B \quad (3)$$

The relevant pressure differences can be calculated with equations (4) – (7):

$$\Delta p_{A1} = p_{2,1} - p_{3b,1} \quad (4)$$

$$\Delta p_{B1} = p_{1b,1} - p_{4,1} \quad (5)$$

$$\Delta p_{A2} = p_{2,2} - p_{3b,2} \quad (6)$$

$$\Delta p_{B2} = p_{1b,2} - p_{4,2} \quad (7)$$

With the measured values of $\Delta p_{A1}$, $\Delta p_{B1}$, $\Delta p_{A2}$, $\Delta p_{B2}$, $q_{vi,tot1}$ and $q_{vi,tot2}$ the leakage factors $C_A$ and $C_B$ can be calculated.

If the two measurements are finished, the transfer ratio of the supply side $R_s$ can be calculated. For that calculation, firstly the pressure differences $\Delta p_{A,\mathrm{ref}}$ and $\Delta p_{B,\mathrm{ref}}$ at reference conditions are determined. These pressures can e. g. be measured at the test set-up for thermal tests. Then the supply leakage air flow rate at reference conditions is determined by equation (8):

$$q_{vi,s} = \Delta p_{A,ref} \cdot C_A \quad (8)$$

Finally, the transfer ratio of recirculated air in the supply air stream for RVUs with plate heat exchangers is expressed by equation (9):

$$R_s = \frac{q_{vi,s}}{q_{v,ref}} \quad (9)$$

This should be equal to the internal leakage as determined with the In-duct method.

For rotors the carry over of air volumes in wheel and the rotor speed is not included in equation (9). Therefore, the transfer of this effect has to be added. This total ratio with recirculated air for RVUs with rotor is defined by equation (10):

$$R_s = \frac{q_{vi,s} + q_{v,co}}{q_{v,ref}} \quad (10)$$

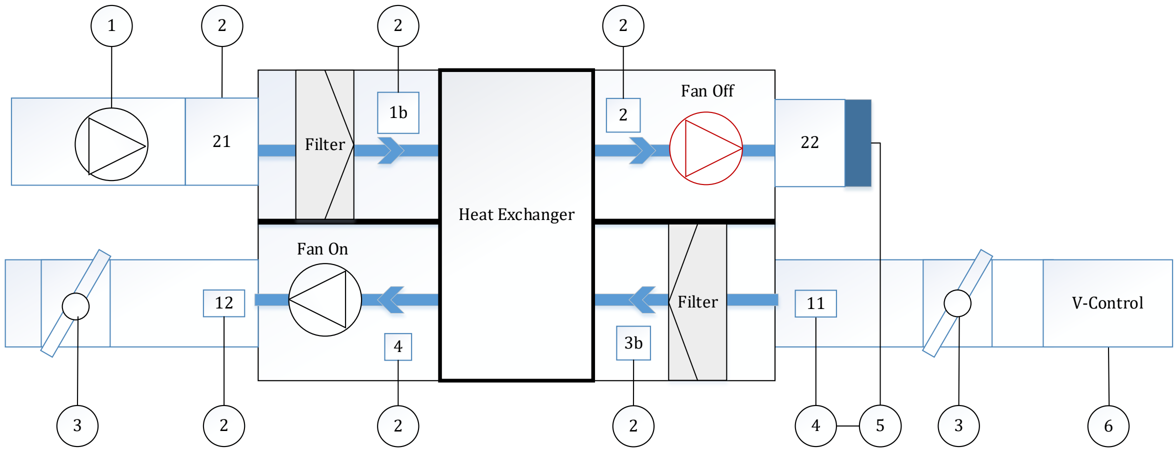
where $q_{v,co}$ is the transferred air by carry over. The calculation can be found in literature or manufacturer information e.g. [8].

## 4.2 Test setup and procedure

The APM is performed with one fan of the RVU switched on and the other one switched off. The measurement setup is pictured in **Fig. 6**.

The airflow side where the fan is switched off is treated as with the pressure method. That is, the pressure difference between this airflow side and the environment is 0 Pa. This is achieved by an adjustable auxiliary fan connected to the unit. The supplied air corresponds to the internal leakage air flow and is measured. On the airflow side with the fan switched on, the settings are varied. It is recommended to start with the reference air flow and a unit pressure of 50 Pa (distributed 1/3 and 2/3 on exhaust and extract air as described for the In-duct method).

For the other test points, the setting of the pressure ratios and thus the leakage airflows should be varied so that the ratios of the pressure differences 1b - 4 and 3b - 2 are clearly different between the test points.




**Legend for exhaust fan on:**
1) Adjustable fan and rotary displacement meter
2) Pressure gauge connection to ambient
3) Iris diaphragm (or alike) for adjusting the pressure
4) Differential pressure gauge connection 22-11
5) Differential pressure gauge connection 22-ambient
6) Air flow measuring equipment

11 = Extract Air
12 = Exhaust Air
21 = Outdoor Air
22 = Supply Air (sealed)

**Fig. 6 –** Test setup APM

This can be achieved by varying the setting of throttle valves installed at the duct connections.

For measurements the reference air flow was kept constant and only the pressures were varied.

Even though the model only requires data from two test points, it is recommended to perform at least five points. Some of the test points can be obtained by changing the two airflow sides.

### 4.3 Measurements and test results

Examples of measurement results of the APM for the Plate RVU are shown in **Tab. 5**. The measured value of the In-duct method with the given pressures was $R_s$ = 0.6 % as described in **Tab. 1**.

**Tab. 5 –** Examples of four Measurement Points (MP); Plate RVU with APM

| | MP 1 | MP2 | MP3 | MP4 |
|---|---|---|---|---|
| $\Delta p_{A1}$ | -58 | -58 | -50 | -50 |
| $\Delta p_{B1}$ | -106 | -106 | -99 | -99 |
| $\Delta p_{A2}$ | -50 | -79 | -79 | -140 |
| $\Delta p_{B2}$ | -99 | -123 | -123 | -190 |
| $q_{v1}$ | -2.3 | -2.3 | -2.1 | -2.1 |
| $q_{v2}$ | -2.1 | -2.9 | -2.9 | -4.1 |
| $C_A$ | 0.013 | 0.021 | 0.019 | 0.002 |
| $C_B$ | 0.014 | 0.010 | 0.012 | 0.020 |

The mean value of the four measurements is $C_A$ = 0.013 and leads to the calculated $R_s$ = 0.38 %.

The measurements carried out for the Rotary RVU are shown in **Tab. 6**. In these measurements the wheel switched off (0 rpm).

The measured value of the In-duct method with the given pressures was $R_s$ = 0.9 % (0 rpm) as described in **Tab. 1**.

**Tab. 6 –** Four realistic Measurement Points (MP); Rotary RVU with APM

| | MP 1 | MP2 | MP3 | MP4 |
|---|---|---|---|---|
| $\Delta p_{A1}$ | -109 | -109 | -118 | -147 |
| $\Delta p_{B1}$ | -194 | -194 | -205 | -233 |
| $\Delta p_{A2}$ | -147 | -99 | -147 | -99 |
| $\Delta p_{B2}$ | -233 | -186 | -223 | -186 |
| $q_{v1}$ | -13.9 | -13.9 | -14.5 | -16.7 |
| $q_{v2}$ | -16.7 | -13.2 | -16.7 | -13.2 |
| $C_A$ | 0.003 | 0.016 | 0.017 | 0.007 |
| $C_B$ | 0.070 | 0.063 | 0.061 | 0.068 |

The mean value of the four measurements is $C_A$ = 0.016 and leads to the calculated $R_s$ = 0.34 %.

It is worth mentioning that in the example of this Rotary RVU, the additional air transfer ratio due to carry over is 2.5 % at the nominal wheel speed of 8 rpm. This puts the difference between the APM and In-duct method (with 0 rpm) into perspective.

### 4.4 Measurement Uncertainty

The measurement results were evaluated hence their measurement uncertainty, see **Tab. 7**. The declared measurement uncertainties of the single quantities are higher than the measurement uncertainty of the used measurement instruments. The reasons are effects as fluctuation and not ideal position of probes. Nonetheless, the result shows this influence is not crucial. The extended measurement uncertainty of the pressure difference is relatively high, because besides the uncertainty of the pressure probes, the setting of the pressure tabs is difficult (and will presumably differ in testing by different laboratories). The calculations were carried out with the software GUM Workbench [9].

**Tab. 7 –** Comparison of measurement uncertainties

| $C_A$ [(m$^3$/h)/Pa] | In-duct | APM |
|---|---|---|
| Plate RVU | 0.020 ± 0.002 | 0.012 ± 0.019 |
| Rotary RVU | 0.045 ± 0.004 | 0.017 ± 0.034 |

For the internal leakage of the Plate RVU, the high relative uncertainty of the APM is not crucial. An internal leakage of $R_s$ = 0.4 ± 0.4 % still confirms, that this RVU is in Class C2, even if for the classification the measurement uncertainty would be added to the probable value.

Also, for the Rotary RVU a result of $R_s$ = 0.9 ± 0.4 % (rotor speed 0 rpm) has no big impact on the classification, especially if it is considered that the carry over at nominal wheel sped has a much higher influence.

### 4.5 Conclusions of the APM results

In conclusion, the relative uncertainty in these examples is high, but the absolute uncertainty is in an acceptable range, at least for a first application example of the APM. It is expected that a similar absolute uncertainty would be achieved for RVUs with higher internal leakage rates which then means a lower relative uncertainty.

In a master student's project [10], some of the previous findings could be taken into account. Furthermore, an additional RVU with a different positioning of the fans was investigated. In summary, it can be said that a smaller absolute measurement uncertainty could be achieved and the APM worked with a different fan configuration.

## 5. Discussion

Both tested RVU's have a good tightness and thus a low internal leakage rate. In this respect, the results of the APM are promising that low leakage rates could be confirmed. Also, the results are in the range of the In-duct method. Even, the relative measurement uncertainty has been high, it has had no impact on the classification of the two investigated RVU's. Nevertheless, the APM needs some further development to reduce the measurement uncertainty. For example, testing points with supply air fan switched off (and extract air fan running) and additionally testing points with extract air fan switched of (and supply air fan running). Thus, increasing of the number of the testing points (to a total of about 10).

Also, a model with power functions for leakage air flow could be evaluated. In this project, numerical test calculations were carried out to compare the linear with an exponential function. For the performed measurements in this project the impact on the result of $\boldsymbol{R_s}$ and the measurement uncertainty was marginal.

An open question is whether all types of RVU are suitable for APM. The pressure differences during the APM could deform a sealing differently than under reference conditions. If a leakage factor is not constant, then the APM will not work.

## 6. Conclusion

For laboratories with tracer gas equipment, the APM will not lead to easier and faster testing; on the contrary, the In-duct method will remain more efficient. However, there are only a few accredited laboratories in Europe that have RVU testing with tracer gas in their scope. In comparison, there are dozens (if not hundreds) of manufacturers' laboratories and also independent testing bodies that do not have tracer gas equipment or do not use it in the accredited area. However, these laboratories are well qualified for pressure and air flow measurements, which are required for the APM. The main advantage of the APM is that these laboratories can achieve comparable results to the in-duct method without tracer gas measurement. In addition, the APM provides a good understanding of an RVU, as it provides information about leakage on the supply air side, leakage on the exhaust air side and the pressure distribution in the RVU.

All in all, the APM is a good first approach to determine the leakage of an RVU without tracer gas and gives the opportunity to compare the different unit types with each other. Nevertheless, more work for the further development of the test procedure and more experience is needed.

## 7. Acknowledgement

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### *Data Statement*

The datasets generated during the study are not publicly available because they are still used in a research project that will be continued but the data can be obtained by a request to the authors.