# DEVELOPMENT OF A DECENTRALIZED AND COMPACT COMFORT VENTILATION SYSTEM WITH HIGHLY EFFICIENT HEAT RECOVERY FOR THE MINIMAL INVASIVE REFURBISHMENT OF BUILDINGS

Janez Zgaga[*1], David Lanthaler[1], Christoph Speer[2], and Rainer Pfluger[2]

*1) Fraunhofer Innovation Engineering Center,*
*Fraunhofer Italia Research*
*Via Macello 57*
*Bolzano 39100, Italy*
**Corresponding author: janez.zgaga@fraunhofer.it*

*2) Institute for Structural Engineering and Material Sciences, University of Innsbruck*
*Technikerstraße 13*
*Innsbruck 6020, Austria*

## ABSTRACT

To ensure adequate indoor air quality, ventilation is necessary in new constructions as well as in modernized existing buildings. In order to minimize energy losses, ventilation systems with integrated heat recovery should be used. Particularly in building refurbishment, ventilation systems need to be designed as compact as possible, to allow a subsequent integration in the existing building stock. Ventilation systems in which one component is responsible for ventilation and simultaneously for heat recovery are well suited for this application area. Already existing systems like the Heat Recovery Centrifugal Fan (HRCF) have a systemic performance limitation regarding ventilation and heat recovery efficiency. These disadvantages still prevent the wide usage in building renovation.

Based on the already known HRCF principle and the unsatisfying market-ready solutions, the “Interreg IV” project VENT4RENO, in which the Fraunhofer Innovation Engineering Center (Italy) and the University of Innsbruck (Austria) collaborate, has the aim to improve the efficiency of such systems and its management, so that they can compete with other systems offered on the market. Beside the design of a compact device, heat recovery, anti-freeze protection, absorption of condensate as well as device control management should be enhanced. In this regard, the University of Innsbruck optimizes the aero- and thermodynamic aspects of the system, while the Fraunhofer Innovation Engineering Center implements the enhanced automatic control as well as the usability of the device.

The modified concept of the Counterflow Heat Recovery Fan (CHRF) allows enhancing ventilation and heat recovery performance at the same time, by using only one cross flow fan for the generation of both flows. Thereby the blades work simultaneously as fan and heat exchanger. Moreover, this modified concept has an integrated systemic anti-freeze protection and allows moisture recovery, making a condensate drain superfluous. A summer bypass is integrated in order to switch off the heat recovery to avoid overheating in the warm season.

Besides measuring and reacting to air parameters like temperature, humidity and carbon dioxide levels, the device needs airflow balancing. By using just one fan, a balance mechanism must control the airflow rate between the intakes. This is essential to avoid over or under pressure, which can cause low efficiency due to leakages or even mold formation. Different operating scenarios were identified, which the device handles automatically or semi automatically. In the latter case, the user can intervene, if wanted, via control panel.

The characteristics of this CHRF concept makes it well suited for decentralized ventilation in refurbished building stock. The simple and compact design allows wall and envelope integration as well as low running costs.

**KEYWORDS**

Heat Recovery Centrifugal Fan (HRCF)
Counterflow Heat Recovery Fan (CHRF)
Sustainable Building Refurbishment
Demand-controlled Ventilation Strategy
Airflow Balancing Mechanism

# 1 INTRODUCTION

Nowadays good climate comfort in new buildings is a matter of course, but having the same standards also in refurbished buildings, requires substantial interventions together with continuous and major energy wastage. Since both the number of buildings and their life cycle duration grow, reducing their energy usage has become a major priority and challenge. In the European Union 40% of the total energy consumption is caused by buildings (European Parliament and the Council, 2010). The directive 2010/31 published by the European Parliament and Council in May 2010 (based on the Kyoto-Protocol), provides that the entire energy consumption in the European Union has to be reduced by 20%, compared to the energy consumption in 1990, until 2020 (European Parliament and the Council, 2010). To fulfill this objective while ensuring climate comfort and efficiency, ventilation systems should use integrated heat recovery. Given that the existing building stock outnumbers by far the number of new buildings, ventilation systems should be designed in such a way, to allow a minimally invasive installation and therefore ensure low renovation costs.

The components of such a system should be multifunctional to allow a very compact system design. There are already existing HRCF systems (Heat Recovery Centrifugal Fan) based on this concept, but these market ready products have several weaknesses in terms of thermal and electric efficiency as well as usability. These disadvantages still prevent a wide market penetration of this type of system.

Based on the already known HRCF principle and unsatisfying market-ready solutions, the “Interreg IV” project VENT4RENO, in which the Fraunhofer Innovation Engineering Center (Italy) and the University of Innsbruck (Austria) collaborate, has the aim to improve the efficiency of such systems and its management, so that they can compete with other systems offered on the market. Beside the design of a compact device, heat recovery, anti-freeze protection, absorption of condensate as well as device control management should be enhanced.

# 2 OVERALL DESIGN CONCEPT AND FEATURE DESCRIPTION

The main components of state of the art ventilation systems with heat recovery are two fans for extract/exhaust air and outdoor/supply air as well as a heat exchanger. Combining these three components into one single component enables the chance to develop very compact ventilation systems. Based on the studies of Dr.-Ing. Sprenger and De Fries (De Fries, 1969) for the development of a rotating heat exchanger (Heat Recovery Centrifugal Fan, HRCF) the company Josef Friedl GmbH has developed the “Frivent®-Wärmerückgewinner” (Josef Friedl GmbH, 2011). As shown in Figure 1, this system aspirates the cold outdoor air as well as the warm extract air separately and axially in the center and blows out the supply and exhaust air radially using the centrifugal force of a rotating porous foam. While the airstreams pass the foam, thermal energy is transferred from one to the other airflow.

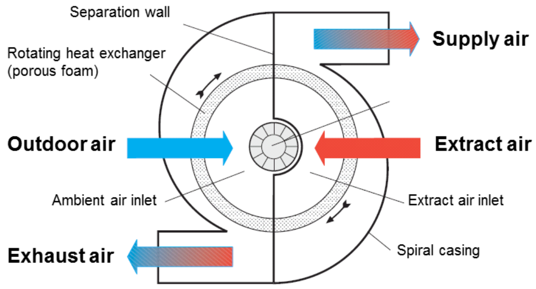


Figure 1: Functional diagramm of the cross section of the Frivent® HRCF (Josef Friedl GmbH, 2011).

The main advantages of this concept are a very simple, cost-efficient and compact ventilation unit design. The disadvantages, like limited fluid-mechanical and thermal efficiency, on the other hand prevent the widespread use in building modernization. The objective of the research project is the development of an innovative decentralized ventilation unit with heat recovery, which maintains the advantages of the HRCF and, at the same time, increases the fluid-mechanical and thermal efficiency. An initial concept idea, where the porous foam was replaced by a cross flow fan and the flow conduction was modified, has been presented in (Pfluger, et al., 2013). Through these modifications, the heat recovery rate can be increased from less than 50% (Josef Friedl GmbH, 2011) to more than 80% (Pfluger, et al., 2013) because the flow regime is switched to a counterflow principle. In addition, the fluid-mechanical efficiency can be improved because the cross flow fan is much better suited to generate airflows. Both air aspiration and air blow out is done radially through the fan blades. Walls in the center of the cross flow fan separate the two airflows and also induce them to change level, in order to use the counterflow heat recovery twice. The results of the numerical CFD simulation of the modified concept can be seen in Figure 2. A detailed description of the flow behavior can be found in (Pfluger, et al., 2013).

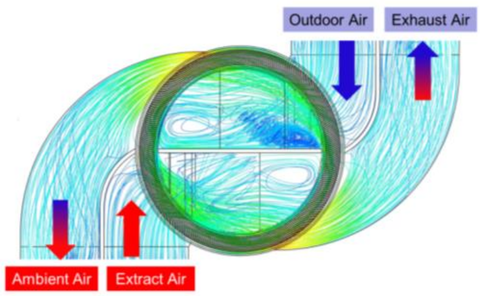


Figure 2: Numerical CFD simulation of the modified concept.

Due to different flow resistances caused by filters or ventilation ducts, the airflows might not be equally balanced. An additional adjustable bypass airflow, which passes through the unit without level change is implemented to enable a volumetric flow balance. To avoid over or under pressure inside the building, the additional bypass airflow can compensate for eventual pressure drops. Moreover, during the warm season the system can operate in pure bypass mode to disable the heat recovery. In this case, both airflows pass the unit without changing level; in this way no heat transfer from the warmer to the colder air stream takes place. An additional advantage of the system is the automated moisture recovery during cold periods. Condensed water of cooled extract air can be absorbed by heated outdoor air, which on the one hand prevents dry supply air and on the other hand prevents the icing of the cross flow fan.

# 3 MECHATRONIC COMPONENTS AND VENTILATION CONTROL

Before implementing the design concept into a physical prototype, a topology of the system has been created. This gives an overview of all the information (flow rate, temperature, pressure, motor voltage, etc.) and mechatronic components (sensors and actuators) that are needed to control and manage the device. Figure 3 shows the system topology and the correlations, flows, connections and interaction between airflows, mechanical and electrical components.

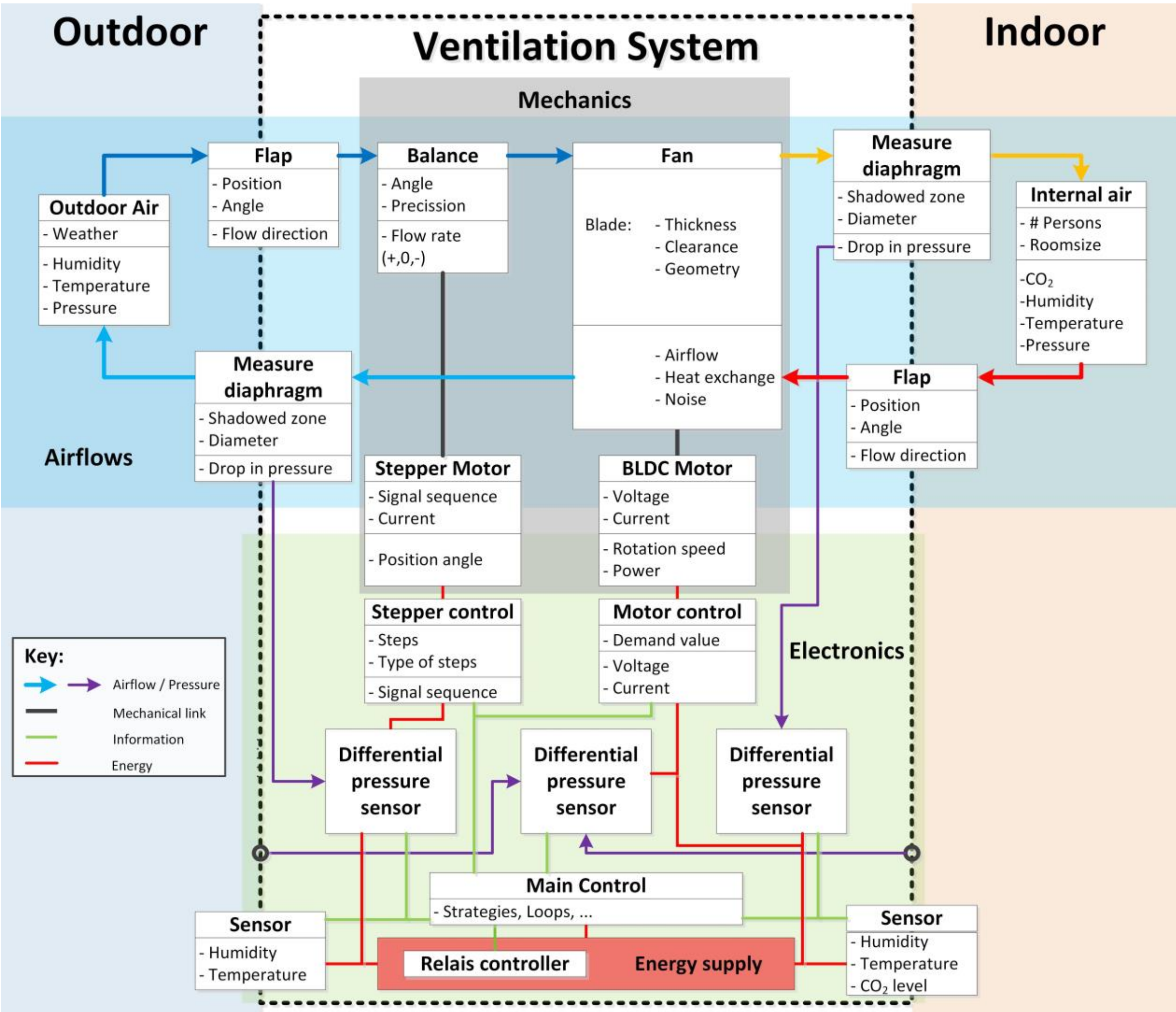


Figure 3: System topology of the design concept.

## 3.1 Sensors, actuators and ventilation strategy approaches

Depending on the usage scenario and the information given from the sensors (temperature, humidity, $CO_2$ level, etc.), a certain target airflow rate is preset. The fan motor is led by this target airflow rate and any measured actual/target deviation is dynamically compensated in an inner control loop. The balanced ratio between exhaust and outdoor airflow rate is fundamental for an efficient indoor ventilation system. To guaranty a symmetrical flow rate, the modified design concept uses measuring diaphragms at each inlet (supply and exhaust port) with differential pressure sensors. The respective airflow rates can be derived from the dynamic pressure, which the differential pressure sensors can determine. In addition, to prevent dangerous scenario like fireplaces interacting with the ventilation system, a highly

sensitive differential pressure gauge monitors the barometric differential pressure between inside and outside.
The most commonly used control strategies are airflow based; alternative strategies to realize a $CO_2$-based demand-controlled ventilation are discusses in the work of Nabil Nassif (Nassif, 2012). This concept implies the monitoring of the indoor air quality (IAQ) by the use of low-cost sensors, in order to add the $CO_2$ level as process variable. Based on the geometry of the fan and due to superior energy efficiency a speed variable high torque brushless direct current (BLDC) motor with integrated hall-sensors is used.

### 3.2 Airflow balancing mechanism

It is important to ensure equal flow rates in both directions to avoid low efficiency due to leakages or even high moisture in walls (mold formation) caused by over or under pressure. The airflow balancing between both airflows is realized in a non-common way, by introducing a small imbalance of the intake apertures. This non-adequate difference causes a significant offset flow in one direction. In combination with a flow-regulating iris diaphragm in the other intake aperture, positive, zero or even negative balance rates can be obtained. Normally the system tries to stabilize the two synchronous flows to prevent the deficiencies. The iris diaphragm was chosen because round apertures are most suitable concerning flow rates.

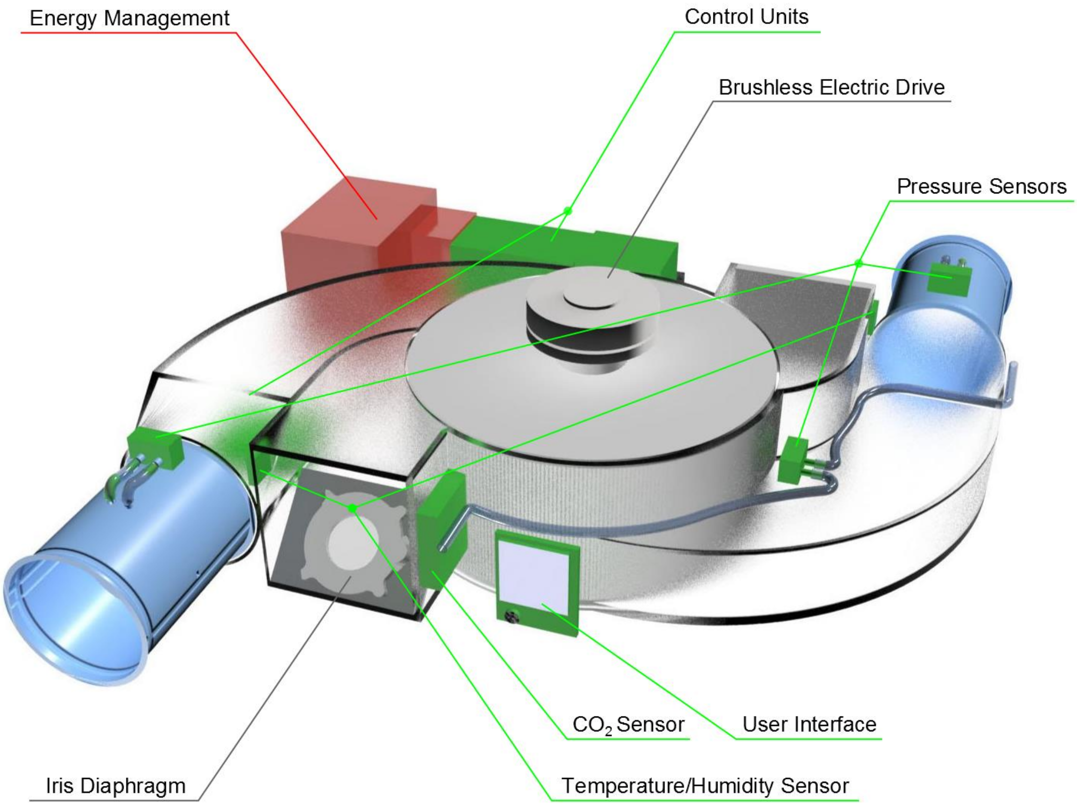


Figure 4: Concept drawing and positioning of the mechatronic components.

A concept drawing and the preliminary positioning of the mechatronic components are shown in Figure 4. The colors used in Figure 4 correspond to the cluster colors in Figure 3.

## 4 SCENARIO-BASED VENTILATION STRATEGY AND DEVICE USABILITY

The usage of this kind of ventilation system depends on various and some non-daily scenarios. This requires that several scenarios can occur without failure of the ventilation system. Also after installation, only a minimum of maintenance should be required. In the following three scenarios will be discussed.

### 4.1 Ventilation in combination with a fireplace

If the system is installed in a room near an integrated fireplace, the sensors must be able to detect a sparked fire. The fire will be detect by recognizing an underinflation caused by outdoor back pressure. The system detects this condition within a few seconds and switches itself off.

### 4.2 Summer bypass

In the warm season, it is important to have an air exchanger without heat recovery. In summer nights, when the outdoor temperature drops and gets lower than the indoor temperature the ventilation system can be used as indoor air cooler, exchanging fresh outdoor air with warm indoor air. The design concept includes two additional ducts and two switchable flaps, which in summer mode position only allow the airflows to pass through the fan on the upper, respectively lower side. Thus, heat exchange can only occur by the thermal longitudinal conduction of each blade, but no more by convection. This - in this case - parasitic heat exchange is reduced to a minimum by manufacturing the fan out of material with low thermal conductivity. This does not affect the normal heat exchange ability, because the thermal conductivity coefficient has no impact on thermal storage capability.

### 4.3 Indoor air quality (IAQ) control strategy

Besides discussing common controlled ventilation strategies, (Mossoly, et al., 2009) also present two new ventilation strategies using a genetic algorithm. The goal of the first strategy is to maintain the temperature set point while assuring indoor air quality (IAQ). The second strategy controls the supply air rate and temperature to ensure an acceptable thermal comfort and IAQ. Comparing these two strategies with conventional control strategies that only maintain a temperature set point results in considerable energy savings. Conventional control strategies use only a constant airflow rate to guarantee an acceptable IAQ.
The multi strategy modes of the modified design concept for the ventilation system are based on IAQ (more specific, the indoor $CO_2$ level), thermal and overall efficiency and maximum airflow (for non-common situations).
While running in the IAQ-based mode, the carbon-dioxide concentration is measured and ventilation runs to keep the $CO_2$ level under a certain level. Lowest possible energy consumption is the target of the efficiency-based mode. The ventilation system tries to run in the most efficient way regarding the total energy consumption, but still monitoring the IAQ and remaining below the maximum acceptable carbon-dioxide concentration. The maximum airflow mode, often called “party mode”, keeps the fan motor at full speed. This is used for rooms and situations that needs intensive ventilation.
On top of these modes a control loop monitors that the air exchange always complies with the legal required minimum and the $CO_2$ level doesn’t exceed legal limits. At the highest level, a control loop guarantees maximum safety by shutting down the ventilation system in potential failure-cases. A graphical user interface, consisting of a color display with joystick, allows the change of usage modes and displays warning messages in failure-cases.

## 5 CONCLUSION

An important part of this research project is of course the construction and realization of a functional prototype to verify and validate the calculated results. The components used in the modified concept are shown in Figure 4: Concept drawing and positioning of the mechatronic components. At the moment the prototype is not yet fully engineered, nevertheless Table 1 gives an overview of the expected characteristics. The major improvements of the modified design concept are an enhanced counterflow concept in combination with an efficient IAQ-based ventilation control. The theoretical efficiency improvement between the modified counterflow concept and the existing co-flow concept is expected to be more than 30%.

Table 1: Comparison between the existing system and the modified design concept

| Feature | Existing system | Modified design concept |
|---|---|---|
| Dimensions | 570 x 460 x 160 mm | 560 x 350 x 160 mm |
| Fan outer diameter | Ø 250 mm | Ø 260 mm |
| Fan width | 60 mm | 120 mm |
| Air flow | 100 m³ per hour | 100 m³ per hour |
| Rotational speed | 15,2 rotations per second | 20 rotations per second |
| Heat recover efficiency up to | 48% | 80% |
| Summer bypass | No | Integrated |

For the modified design concept a controlled balance mechanism, which regulates the flow rate with a maximum differential flow rate of 10%, is essential to avoid the risk of permanent excess or negative pressure. It is hardly possible to give a forecast about the real efficiency of the two control strategies. Upcoming tests in the climatic chamber of the University of Innsbruck will demonstrate and prove how close the measured values of the prototype will meet the theoretical calculated characteristics.

## 6 ACKNOWLEDGEMENTS

This work was carried out as part of the research project VENT4RENO within the framework of the funding program “Interreg IV” of the European Regional Development Fund.

## 7 REFERENCES

De Fries, J. R., 1969. *Heat Recovery Centrifugal Fan.* US, Patent No. 3456718.

European Parliament and the Council, 2010. *Directive 2010/31/EU of the European Parliament and of the Council of 19 may 2012 on the energy performance of buildings,* s.l.: Official journal of the European Union.

Josef Friedl GmbH, 2011. *Frivent-Wärmerückgewinner - Technische Daten Abmessungen.* [Online] Available at: http://www.frivent.com/userdata/4034/uploads/Produkte/pdf-files/WRG-Katalog-DE-2011.pdf

Mossoly, M., Ghali, K. & Ghaddar, N., 2009. Optimal control strategy for a multi-zone air conditioning system using a genetic algorithm. *Energy 34*, pp. 58-66.

Nassif, N., 2012. A robust CO2-based demand-controlled ventilation control strategy for multi-zone HVAC systems. *Energy and Buildings vol. 45*, February, pp. 72-81.

Pfluger, R. et al., 2013. Entwicklung eines hocheffizienten Ventilators mit integrierter Gegenstromwärmerückgewinnung für den Einsatz in der Gebäudemodernisierung. *Bauphysik*, August, pp. 242-249.