Development of a compact Counterflow Heat Recovery Fan

With the combination of two fans and a heat exchanger in one single component there is the possibility to design a compact and highly efficient ventilation system especially for use in building modernization. One crossflow fan generates both airflows (outdoor/supply and extract/exhaust air) and simultaneously acts as counterflow heat exchanger. The space between the fan blades is filled with elements which operate as regenerative heat exchanger. Based on the numerical optimization the first laboratory prototype of the single/ double room unit was manufactured. This article is based on a paper presented at the 38th AIVC - 6th TightVent & 4th venticool Conference, 2017 "Ventilating healthy low-energy buildings" held on 13-14 September 2017 in Nottingham, UK.

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To ensure adequate air quality, ventilation is necessary in new buildings as well as in the modernization of existing buildings. Through the installation of a mechanical ventilation system with heat recovery it is possible to provide a controlled air exchange and to reduce the energy loss at the same time. Especially in the refurbishment of buildings space-saving solutions are beneficial. With the goal to construct a compact and cost-saving decentralized ventilation system the CHRF (Counterflow Heat Recovery Fan) was developed. The key component of the CHRF is a rotating crossflow fan, which generates both airflows (outdoor/supply and extract/exhaust) and simultaneously acts as a counterflow heat exchanger. The flow conduction and the manufactured laboratory prototype are shown in **Figure 1**. The system is divided into two levels. Supply and extract air are placed in the first level, outdoor and exhaust air in the second level. Through the stationary inner part of the fan the airflows perform a level change so that the crossflow fan

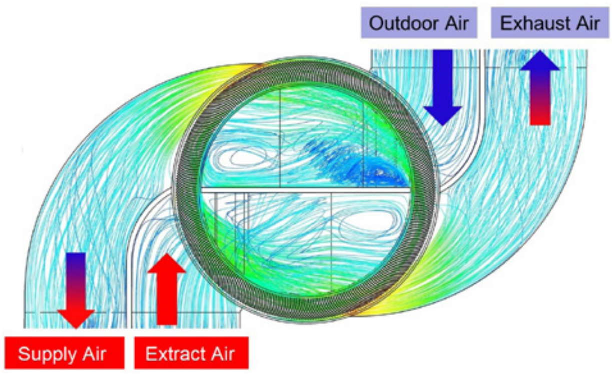

Figure 1. Concept of the Counterflow Heat Recovery Fan. Cross section of the flow conduction (top) [2] and manufactured laboratory prototype (bottom) [3]

acts as a counterflow heat exchanger at both levels. The developed concept of the CHRF, simulation results as well as the measurement results of the laboratory prototype are described collectively in (Speer, 2015a) [1].

The used crossflow fan has to fulfil two functions, generating both airflows as efficient as possible and acting as a highly efficient counterflow heat exchanger. Different possible concepts of this component are presented in (Speer, 2015b) [4], two promising variants are shown in **Figure 2**. Both variants consist of a cross flow fan with 30 blades which mainly generates the air flows and intermediate elements which are responsible for the regenerative heat recovery. These elements can for example be built out of foam material (**Figure 2** (top)), or horizontal thin layers (**Figure 2** (bottom)).

Within the framework of the development of a CHRF for the use as single/double room unit, the flow conduction concept was modified to improve the ventilation efficiency as well as the heat recovery rate by increasing the cross-sectional area used for in- and outlets of the fan. The air flows use a much larger surface area by entering the fan radially, perform a level change along a helix curve and exit the fan again radially. With this flow conduction concept, almost the entire available surface is used to reduce the pressure drop and to increase the heat recovery. The modified concept is shown in **Figure 3**. The cooling mode, described below, is a promising operating mode for night ventilation. Conventional ventilation systems are normally not designed for heat recovery mode in winter and night ventilation in summer because of the wide range of flow range necessary for that concept. The large diameter of the CHRF however provides the option for high flow rates without much additional effort for cost and space. If the unit is integrated in the external wall, the external pressure drop can be reduced to a minimum, which is necessary for high efficient night ventilation at large flow rates. As shown below, the flow rate can be increased by a factor of almost 10 from heat recovery mode to cooling mode.

Modelling and operating modes of the modified concept

In addition to the fluid mechanical and thermal demands we designed the modified concept to meet further requirements. Outdoor air and extract air intake are constructed with large openings to enable the implementation of filters inside the system with low pressure drops. Furthermore, acoustic elements can be installed along the spiral casing to reduce the sound pressure level as close as possible to the point of origin. The acoustic elements can be adjusted to the rotational speed of the main operating modes. The occurring characteristic frequencies of a CHRF and possible solutions to reduce the noise level are discussed in (Speer et al., 2016) [5]. The construction model consists of layers which are responsible for the flow conduction, the stationary inner part, adapters for in- and outlets, a crossflow fan and a metallic plate to connect motor and fan.

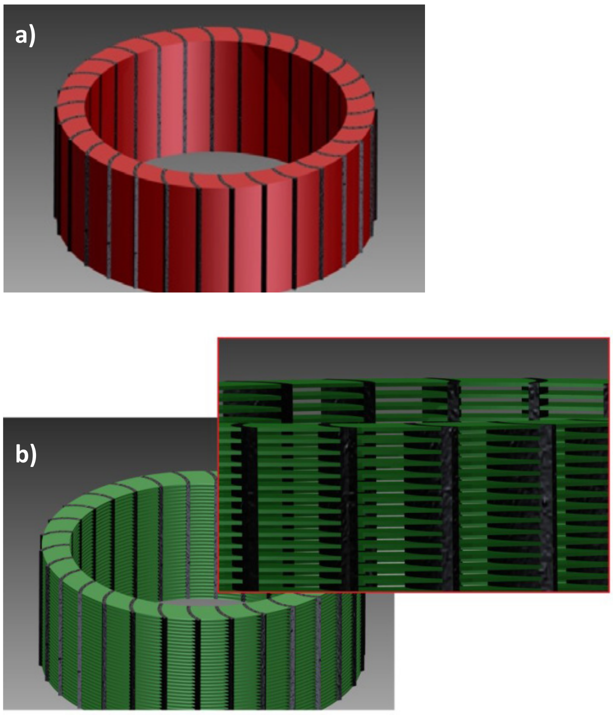

Figure 2. Fan model with 30 blades for the ventilation a) with implemented porous foam and b) with horizontal thin layers for the heat recovery. [4]

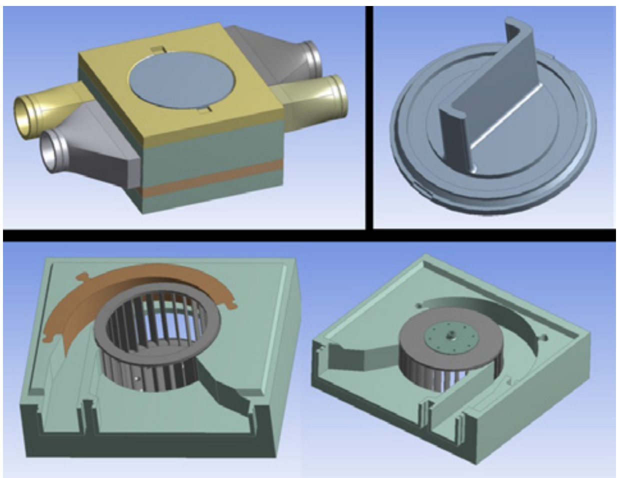

Figure 3. Construction model of the CHRF for the use as single/double room unit.

The flow conduction of the system in the normal heat recovery mode is shown in **Figure 4** (left). Air intake and exit is guided radially through the cross-flow fan. Furthermore, there is the possibility to operate the system in the cooling mode, shown in **Figure 4** (right). In this mode the air intake is guided axially to the centre of the crossflow fan and the air flow is blown out radially through all open flow paths.

The working principle of the CHRF allows generating high flow rates in for night ventilation in the so called "cooling mode" because the already installed fan can be used as a large radial fan and no longer as cross flow fan. There are still questions to work on so that this property can be used in an efficient way and without high installation effort. The definition of flow paths to be used and the implementation of the conduction for the axial outdoor air intake will be part of further research. The dimensions of the single/double room unit, shown in **Figure 3**, are about 350 x 400 x 200 mm with a fan diameter of 190 mm and small enough to integrate it in the external wall insulation.

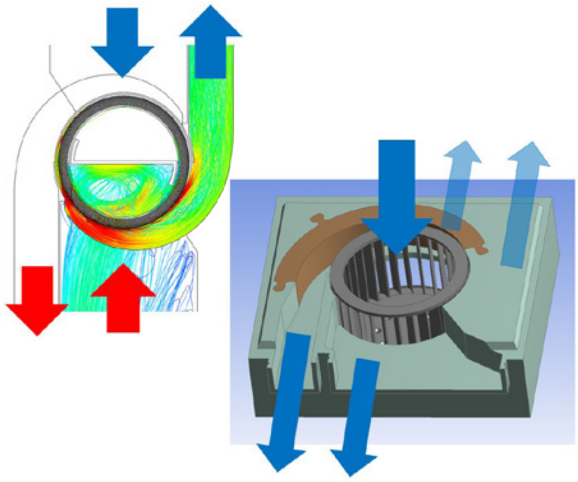

Figure 4. Flow conduction of one airflow of the heat recovery mode (left) [5] and schematic flow conduction of the cooling mode (right).

Simulation results of the modified concept

The fluid mechanical simulation model is based on the construction model in **Figure 3** and the intermediate elements of the crossflow fan are realized as porous media, described in **Figure 2a)**. The achieved flow rates without external pressure and with an external pressure of 50 Pa (at 50 m³/h) at each in- and outlet are shown in **Figure 5**. The flow resistance loss coefficient of the intermediate porous elements is varied between 0 and 300 m^{-1} and the rotational speed of the crossflow fan is set to 15 Hz. Higher rotational speeds up to about 30 Hz are considered, but to ensure the comparison with measurement results of the laboratory prototype we perform the parametric study with a lower speed. The correlation of the rotational speed with the generated flow rate is in this range nearly linear. The variant with external pressure drop and a flow resistance loss coefficient of 300 m^{-1} for the porous elements still leads to flow rates of 28 m³/h at a low rotational speed of 15 Hz. The resulting flow rates for the cooling mode are shown in **Figure 6**. The same variant with external

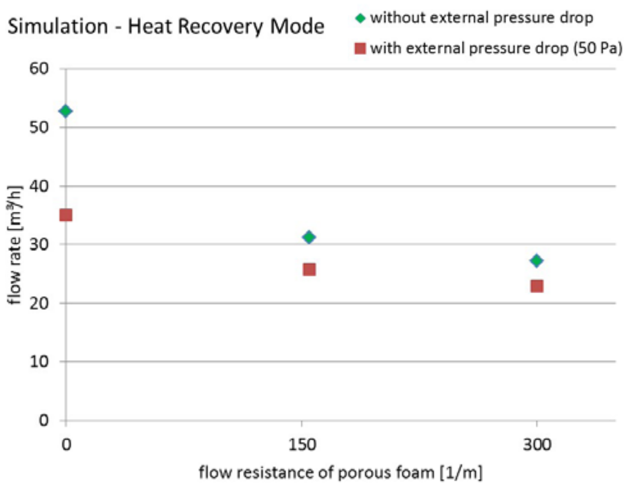

Figure 5. Flow rates of the heat recovery mode at different flow resistance loss coefficients for the porous elements without external pressure (green) and with an external pressure of 50 Pa (red) at each in-/outlet.

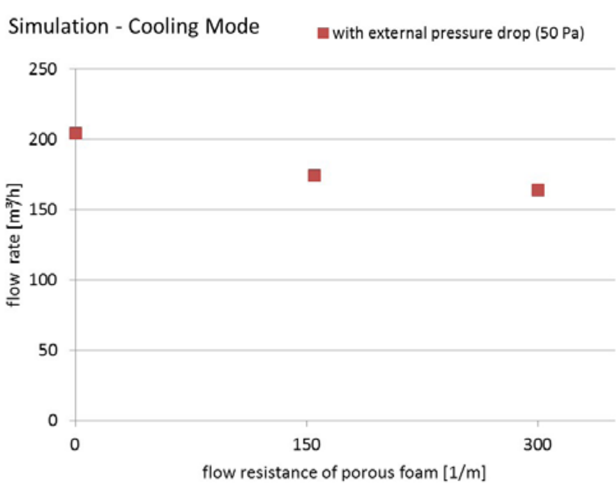

Figure 6. Flow rates of the cooling mode at different flow resistance loss coefficients for the porous elements without external pressure (green) and with an external pressure of 50 Pa (red) at each in-/outlet.

pressure drop and high flow resistance loss coefficient leads to flow rates of 165 m³/h for the cooling mode. If the external pressure drop is reduced and the intermediate porous elements are removed, the flow rate is increased up to 260 m³/h at a low rotational speed of 15 Hz. In order to compare the simulation results with the laboratory measurements which are performed without external pressure drop and porous elements, we get simulated flow rates for these boundary conditions of 53 m³/h for the heat recovery mode and 265 m³/h for the cooling mode.

Measurement results of the laboratory prototype

The manufacturing of the laboratory prototype is based on the construction model in **Figure 3**. All parts of the casing are cut out of polypropylene and the cross flow fan with 30 blades was built by rapid prototyping (3d-plotting). The assembled laboratory prototype is shown in **Figure 7**.

The following measurements are performed without external pressure drop and intermediate porous elements. The rotational speed of the fan is varied between 10 and 20 Hz and the averaged flow rates of the heat recovery mode and the cooling mode are measured. The results are shown in **Figure 8**. For the heat recovery mode, the flow rates are nearly linear in the range of 40–80 m³/h, for the cooling mode in the range of 150–400 m³/h.

Figure 7. Photo of the manufactured laboratory prototype of the CHRF for the use as single/double room unit.

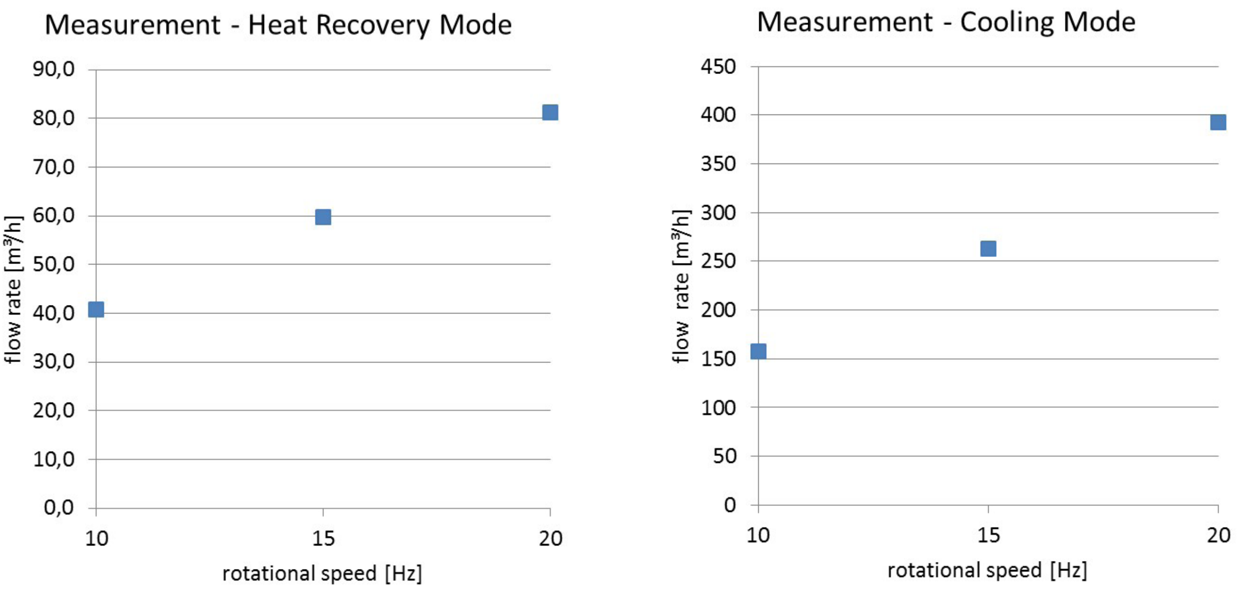

Figure 8. Measured flor rates of the laboratory prototype at different rotational speeds without external pressure and porous elements for heat recovery mode (left) and cooling mode (right).

In **Figure 9** the comparison of the measured flow rate values at a velocity speed of 15 Hz with the simulation results are shown for heat recovery and cooling mode. The measured flow rate of the heat recovery mode is slightly above, the flow rate of the cooling mode is slightly below the simulated value but agrees with good accuracy.

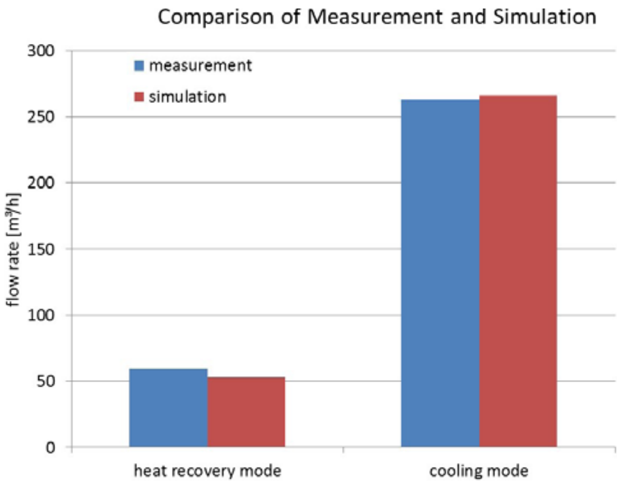

Figure 9. Comparison of measurement and simulation of the flow rates for heat recovery and cooling mode without external pressure and porous elements.

Conclusion

The development of the CHRF for the use as single/double room unit delivers successful simulation as well as measurement results in terms of flow rates which agree with good accuracy. Due to the high flow rates additional rooms could also be supplied. Further laboratory measurement with implemented porous elements are required to ensure adequate heat recovery rates and low internal leakage. Furthermore, the systemic power consumption of the modified concept must be measured to ensure high ventilation efficiency. The promising development of the modified CHRF concept can be scaled up for higher flow rates in order to open up further fields of application. The systemic advantage to generate high flow rates for the cooling mode should be used, hence a simple installation concept, e.g. for wall-integrated operation, should be developed to enable the axial outdoor air intake.

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