Fan coil design was innovated by an additional plenum and a mixing chamber that are usually used in active chilled beams. A fan is source of pressurized air necessary for induction of air flow through a heat exchanger. Air flow from the fan’s plenum through nozzles is used to achieve necessary negative gauge pressure. Dimensions of the unit are within the limits of a conventional fan coil unit, which was achieved by proper selection of the fan and adequate design of the mixing chamber and plenum. The fan electric power was reduced below 10W and noise level was below NC 35 in nominal operating mode of the unit. Results were confirmed by in-house tests on several prototypes for cooling capacities in the range between 800 W and 1300 W.

**Key words:** fan coil unit, noise, efficiency, air induction

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1. Introduction

Fan coils are widespread in large range of sizes and cooling and heating capacities. Versatility, compact and simple design, decentralized, autonomous operation and simple control had impact on relatively frequent use in HVAC systems. Growing demand for both thermal comfort and lower noise levels in residential and commercial buildings are driving force for improvements of existing fan coil technology. In addition, energy efficiency improvements are also beneficial for overall building consumption to certain extent. It was stated that energy consumed by residential and commercial buildings accounts for 20% of the total energy consumed worldwide [1]. The growth rate from 2012 to 2040 was estimated to 1.4% and 1.6% annually for residential and commercial buildings respectively. In the research conducted by EC’s Joint Research Centre, HVAC systems used about 11% of total electricity consumed in Europe in 2007 [2].

Energy efficiency and thermal comfort can be improved by design solutions [3], improved components such as electronically commutated motors, or by advanced system control [4]. Still, the noise remains to be an issue in fan coil operation, both as ducted and non-ducted units.

Units based on air induction gain renowned interest in last few decades. Active chilled beams are partly supplied with pressurized air by central air system (primary air), while the larger part of the air is supplied from the room (secondary air). The primary air is ducted through the plenum to the nozzles in the mixing chamber. Air jet introduces low pressure zone necessary to induce the flow of the secondary air through the heat exchanger to the mixing chamber. Ratio of secondary to primary air flow rate is induction rate which can be in range from 2 to more than 5 in active chilled beams. By careful nozzle design it is possible to achieve very low noise operation of the unit.

The novel fan coil unit is presented in the paper. Both the fan and air induction principle were proposed to be used for air handling from the room. Thus, it was possible to obtain supply air flow rates three to four times higher than the fan flow rate. This evidently leaded to lower fan energy consumption as well as to low noise operation. The basic principle of the unit operation was presented in the paper. In the next sections, prototype unit was introduced as well as measurements and performance determination methods. Short discussion and conclusions followed.

2. Design of the fan coil unit

The basis for the fan coil unit development was existing active chilled beam (ACB) unit FMTBY manufactured by Dadanco. The dimensions of stand-alone vertical fan coil unit for rooms were 1100 mm × 250 mm × 600 mm, Figure 1 and Figure 2. Coil, mixing chamber and nozzles were identical to FMTBY, thus cooling and heating performance of the unit remained the same. Contrary to FMTBY in which the pressurized air is transported to the unit through the ducts from the central system, fan was located in the nozzle plenum providing needed pressure for the nozzles and induction air jet, Figure 3. In the specific arrangement
for the vertical fan coil, the induction air (equivalent to primary air in ACB) inlet is located on the endplate at the side of the unit. This air stream flows through the inlet duct through the fan to the nozzle plenum forming induction jet in the mixing chamber (thinner red lines in figure 4). Inducted air enters the unit through the return grille and coil to the low pressure zone in the mixing chamber (thicker red and blue lines in figure 4). It is also possible to direct the induction air through the coil on the fan suction side in order to attain additional cooling/heating capacity direct the induction air through the coil[5]. Supply air consisting of induction and inducted air exits the unit through the supply grille.

Figure 1. 3D model of Dadanco vertical fan coil unit

Figure 2. Vertical fan coil unit prototype (without unit cabinet)

Figure 3. Cross-section of Dadanco fan coil unit (1 – supply air grille, 2 - unit cabinet, 3 – mixing chamber, 4 – induction nozzles, 5 – nozzle plenum, 6 – fan, 7 – fan suction duct, 8 – return air grille, 9 – drain pan, 10 - coil)

Figure 4. Air flows through the unit
Centrifugal fan is used for induction air stream. The selection of the fan was initiated by high static pressure needed for relatively low volume flow rates. The fan is driven by direct current electronically commutated motor. Operational voltage is 24 V. The fan can be continuously controlled either by the voltage or by pulse width modulation (PWM).

![Image](image.png)

**Figure 5. Visualization of the flow in the mixing chamber of the Spinnaker SV**

**Test and performance calculation methods**

The measurements were conducted to determine pressure in the nozzle plenum, fan voltage and current. Static pressure in the nozzle plenum was measured by Testo 480 differential manometer. The fan voltage and current were set and read on laboratory DC power supply. Cooling and heating performance of the unit was determined for a range of static pressures in the nozzle plenum. Previous performance tests for active chilled beams with identical coil and mixing chamber were used to determine cooling and heating performance of the fan coil unit provided by known relations between static pressure in the nozzle plenum, induction (primary) air flow rate and supply air flow rate. The results were validated by repeated water side performance tests on the fan coil unit as well as supply air tests for known static pressures in the nozzle plenum. Cooling capacity is determined for 7/12°C inlet/outlet water temperature and 27°C dry bulb and 19°C wet bulb air temperature. Heating capacity was determined for 70°C entering water while the water flow rate was kept same as for cooling.

Sound pressure was measured in order to determine the noise emitted by the fan coil unit. Casella CEL 573 was used for measurements. The instrument has capability to provide real time frequency information in the standard and third octave format. Figure 6. It can measure from 5.0 dB to 140 dB rms in 4 measurement ranges – 5-80, 25-100, 45-120 and 65-140 dB.
The measurements were done in five points located 1 m away from the unit, Figure 7. The room noise was kept below 21 dBA for all tests. Third octave bands were measured and the room noise was subtracted for all frequency bands. Subsequently the third octave bands were logarithmically summed in order to obtain octave bands that were presented in the paper.

![Figure 6. Third octave band sound pressure measurement](image)

![Figure 7. Sound pressure measurement points](image)

4. Results and discussion

The cooling and heating capacities for the fan coil unit are given in Table 1 and Table 2 for two and four pipe coil respectively. They are comparable with standard fan coils in the market having in mind similar dimensions, supply air flow rates and operating conditions. Electricity consumption for cooling and heating mode is in range between 4 W and 23 W, Figure 8. Minimum power consumed by the unit is 4 W only, while the unit is capable of delivering 984 W of cooling in that operating regime. Nominal cooling capacity of the unit is 1242 W with 7 W of electricity consumption. The unit is capable of delivering 2 kW in its maximum regime requiring 23 W of electricity.

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Table 1. Cooling and heating capacity of 2 pipe coil unit
Specific consumption of the unit defined as the ratio of electrical power and cooling power is in the range of 0.004 W to 0.012 W per unit of cooling power. The most efficient regimes are in the range of 1000 W to 1400 W for cooling with specific power consumption in the range between 0.004 \( \text{Wel/Wcooling} \) to 0.006 \( \text{Wel/Wcooling} \).

By comparison of supply air flow rate found in Table 1 and Table 2 and flow rate through the fan (primary air in Figure 9) could be seen that induction ratio is 3.75 and above. Although this ratio is increasing towards higher volume flow rates it can be seen that the specific power consumption is increasing, i.e. the fan power consumption is increasing at higher rate. Still, the fan coil energy efficiency ratio (FCEER=186) and the fan coil coefficient of performance (FCCOP=269) are very high. According to Eurovent rating standard for the certification of non-ducted fan coil units [6] the unit should be in energy efficiency class A.

\begin{figure}[h]
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\includegraphics[width=\textwidth]{figure8.png}
\caption{Cooling (solid black line) and heating (red dashed line) capacity of vertical fan coil unit}
\end{figure}

Fan coil noise octave levels for nominal operating point of the unit are shown in Figure 10. Noise in frequency range between 350 Hz and 1000 Hz originates from the fan, both from the flow as well as from the motor. Lower frequency noise comes from the air flow at the inlet and through the nozzles. The most intensive noise is in
the region of air inlet and air outlet as it was expected. The noise is at the limit for acceptance to NC 35 criteria for nominal operating point of the fan coil which was design goal. Still, the measurements were done in ordinary laboratory conditions, 1m away from the unit. The results have to be confirmed by tests in reverberation room in strictly controlled conditions.

Figure 9. Fan air flow rate related to power consumption

Figure 10. Fan coil noise levels (1m away) for nominal operating point

Conclusion

Innovation related to fan coil design was described in the paper. It was shown that by combining active chilled beam and fan coil technology, improvements could be made in unit efficiency and noise levels. The electricity consumption is two to three times lower in comparison to conventional fan coil units. The fan size is reduced significantly, as there is a need to put through only 20% to 25% of overall
supply air. However, the static pressure of the fan is higher in comparison to the conventional fans used in fan coils.

The noise levels of the fan coil are equal to or lower than conventional units. The design of the unit allows the sound insulation space and other sound attenuation measures. According to in-house tests it is expected that NC 35 noise level will be achieved in controlled laboratory conditions measured in line with related noise measurement codes.

Further development is running in several directions. The same principle is already applied to horizontal units for suspended ceiling applications. The unit capacity is going to be increased by engagement of the induction (primary) air for the heat exchange, while maintaining relatively high energy efficiency and acceptable noise level. Also, the fan, the heat exchanger and sound attenuation could be optimized for described application in order to further increase energy efficiency and reduce the noise.

6. References


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