

Energy efficiency measurement of ventilation units

Client:
ebm-papst Mulfingen GmbH & Co. KG

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1 Objective

There are various fan driving systems with different energy efficiency characteristics available for HVAC units. In order to measure the energy efficiency of two fan driving systems, they have been subjected to specific set-up and operation conditions of HVAC units.

The following fan driving systems have been assessed:

- Permanent magnet motor (PM) in standard motor shape with frequency inverter
- Electronically commutated motor (EC) - combined fan/motor unit

2 Test rig

2.1 Set-up of the test rig

The measurements have been carried out at the suction side of a chamber test rig according to DIN EN ISO 5801[1]. The major components of the test rig have been the air flow rate measurement system with its approach and outflow zones, the pressure-controlled support ventilator, the throttle, and the flow rectifiers and conditioners. The test rig consists of a chamber with a clearance of 1,400 mm x 1,600 mm and therefore allows for fan characteristics measurements with air flow rates between 11 m³/h and 11,000 m³/h and chamber pressures of up to ± 5 kPa. The maximum uncertainties of air flow rate and chamber pressure are 1 % and 0.3 % both of the measured values, respectively. The set-up of the test rig is illustrated in Figure 1.

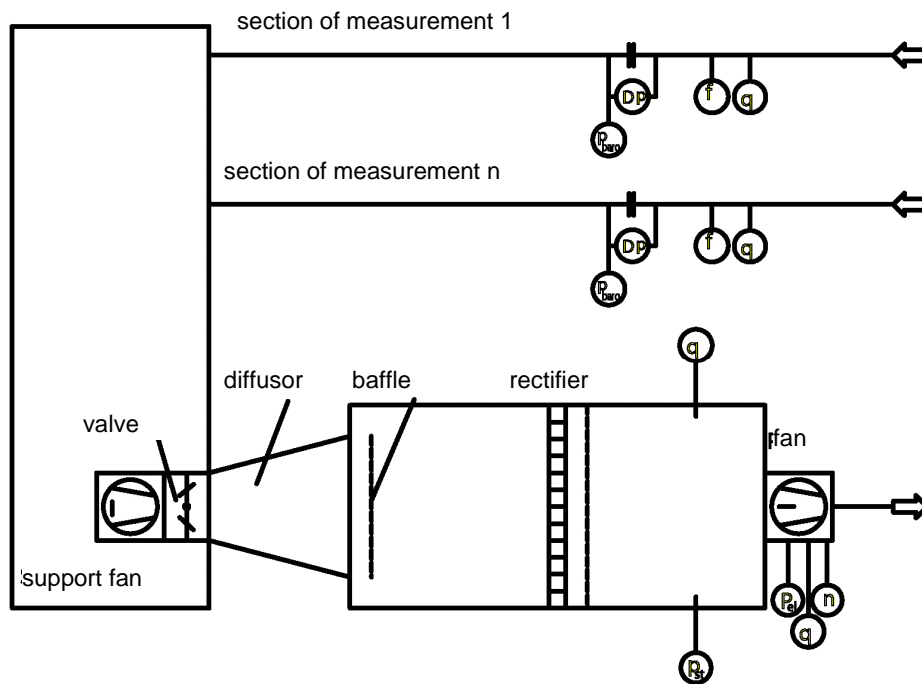


Figure 1: Schema of the test rig

2.2 Test assembly

The influence of different fan driving systems is to be tested for specific set-up and operation conditions of HVAC units. Due to the influence of the walls of the fan casing on both the fan and energy efficiency characteristics, the fan has been installed into an HVAC unit casing. In order to reduce the influence of inlet and outlet, both approach and outflow zones have been installed. Moreover, a perforated plate with an open area of 35 % has been inserted in the approach zone. This test assembly ensures HVAC system specific set-up conditions for the measurements (see Figure 2 and Figure 3).

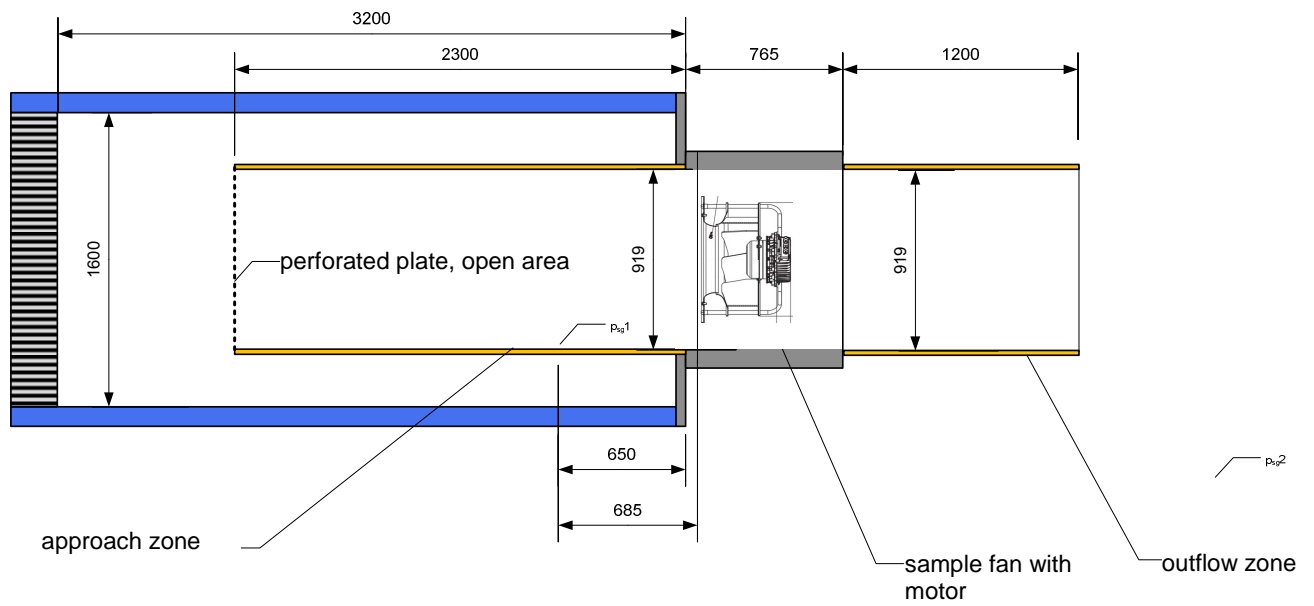


Figure 2: Schema of the test assembly in the chamber test rig

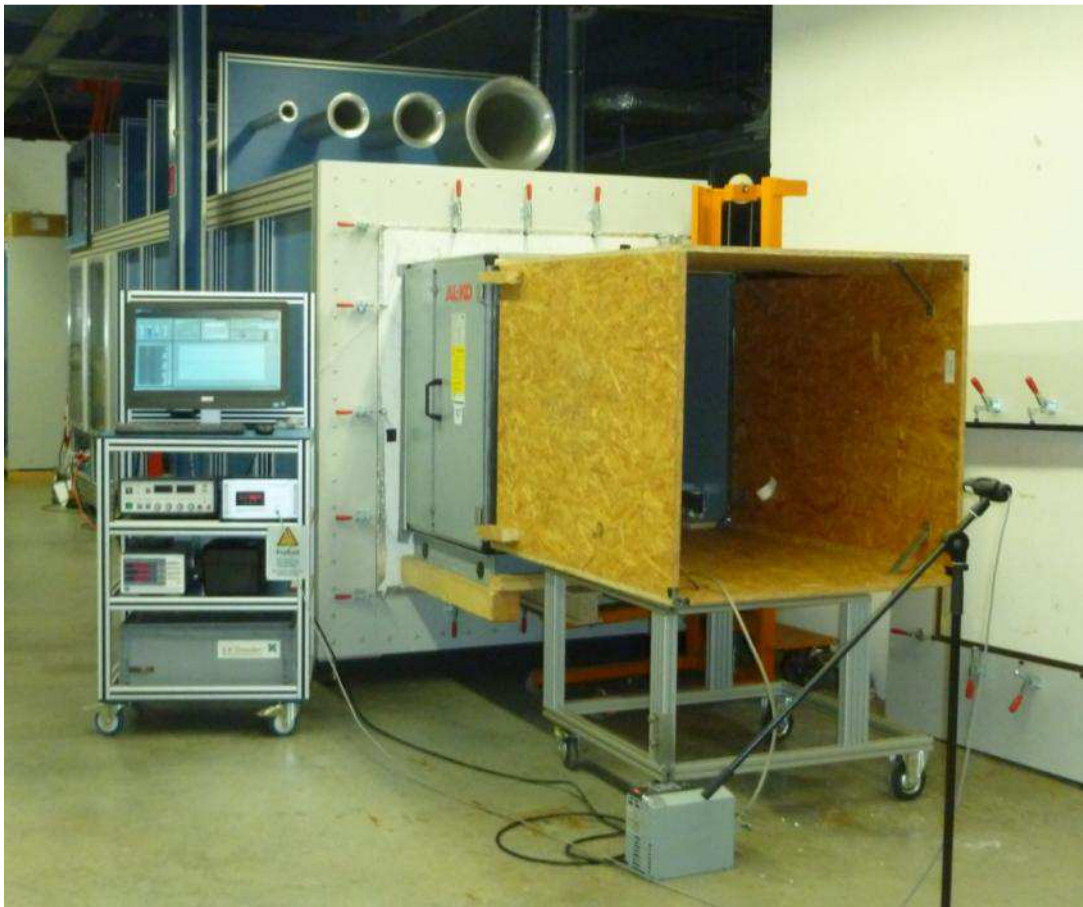


Figure 3: Picture of the test rig with installed sample

3 Test system

3.1 HVAC unit

The client provided the casing of an HVAC unit with an installed fan (see Figure 4 and Figure 5).



Figure 4: HVAC unit casing (ALKO) viewed to outflow

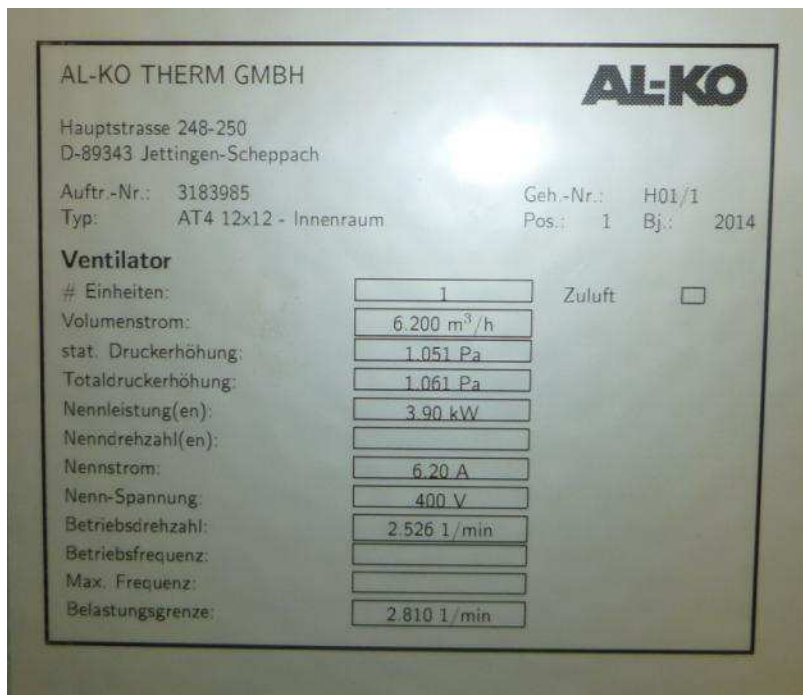


Figure 5: Type plate of the unit casing (ALKO)

3.2 Sample 1 – centrifugal fan with EC motor

The reference unit for the efficiency measurements is a fan unit produced by ebm-papst (type R3G400-XX23-YF), which is a prototype or a model in a pilot lot. The fan unit comprises also the drive and the speed control. For illustrations see Figure 6 and Figure 7.



Figure 6: Picture of sample 1 - centrifugal fan with EC motor

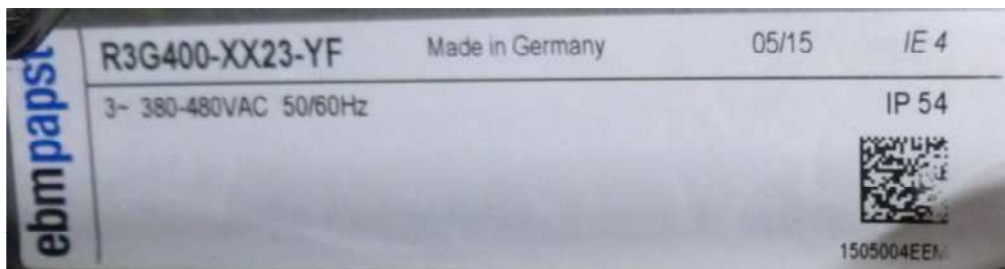


Figure 7: Type plate of fan unit with EC motor

3.3 Sample 2 – centrifugal fan with PM motor

The reference unit for the efficiency measurements is a fan unit produced by ALKO (type RLM E6-0400). The fan is driven by a permanent magnet motor by Lafert and power supplied by a frequency inverter of Danfoss/VLT. For illustrations see Figure 8 and technical data see Figure 9, Figure 10, and Figure 11.



Figure 8: Picture of sample 2 - centrifugal fan with PM motor with standard motor shape

AL-KO		89343 Jettingen	
Tel.: +49(0)8225/39-20		Fax.: 2113	
email: info@al-ko.de		CE	
RLM E6-0400 / 3062805			
GERÄTE-NR. 133-993158-592170/1		HERSTELLJAHR 2014	
VENTILATOR		MOTOR	
n max = 3070	l/min	I N = 8,5	A
Dichte = 1.2	kg/m ³	n N = 3000	l/min
Tmax = 40	°C	P N = 4,0	kW
Ins/Eff = A/STAT		T M max = 40	°C
VSD = instal.		Schutzart IP 55	
ETA opt = 70.3	⊘	Wärmeklasse F	
N ist = 74.6		Stromart 3~	
N(13/15) = 58/62			

Figure 9: Type plate of the fan unit utilised with the PM motor in standard motor shape



Figure 10: Type plate of the PM motor



Figure 11: Type plate of the frequency inverter utilised with the PM motor in standard motor shape

4 Measurements

The measurements have been carried out at the suction side of a chamber test rig according to DIN EN ISO 5801[1] as illustrated on page 6. All samples have been operated for at least six hours in order to reduce the influence of potentially unused bearings. Test series have been carried out for each of the samples in the range of nominal number of revolutions per minute and 2 % of the nominal motor power. Each of the measured point in the characteristics has been obtained in steady state conditions, ensuring standard deviations of both the air flow rate and the

test pressure below 0.3 %. Due to thermal influences, each measurement cycle of a characteristics line required more than one hour. The maximum system efficiencies are provided in Table 1.

Table 1: System efficiencies of the measured characteristics for both systems

rpm [1/min]	max. efficiency (eta) [%]	air flow rate (at eta_max) [m ³ /h]	test pressure (at eta_max) [Pa]	electr. power (at eta_max) [W] (bei eta max)
EC motor / R3G400-XX23-YF				
2837	67	7439	1086	3299
2839	67	7486	1076	3301
2582	67	6651	920	2514
2251	66	5325	782	1735
1905	65	4431	569	1077
1542	60	3714	355	605
1219	55	2999	213	320
894	47	2152	118	150
579	31	1374	50	61
PM motor / RLM E6-0400				
2850	64	5953	1271	3279
2568	63	5429	1010	2406
2282	62	4842	793	1706
1995	61	4094	626	1165
1708	58	3622	435	753
1421	55	2946	308	458
1134	49	2295	201	258
844	39	1625	116	135
557	16	1122	48	92

5 Results and Discussion

The measured efficiency characteristics of the EC fan unit R3G400-XX23-YF (sample 1) exhibits an efficiency above 65 % for a very large air flow rate range (see Figure 12).

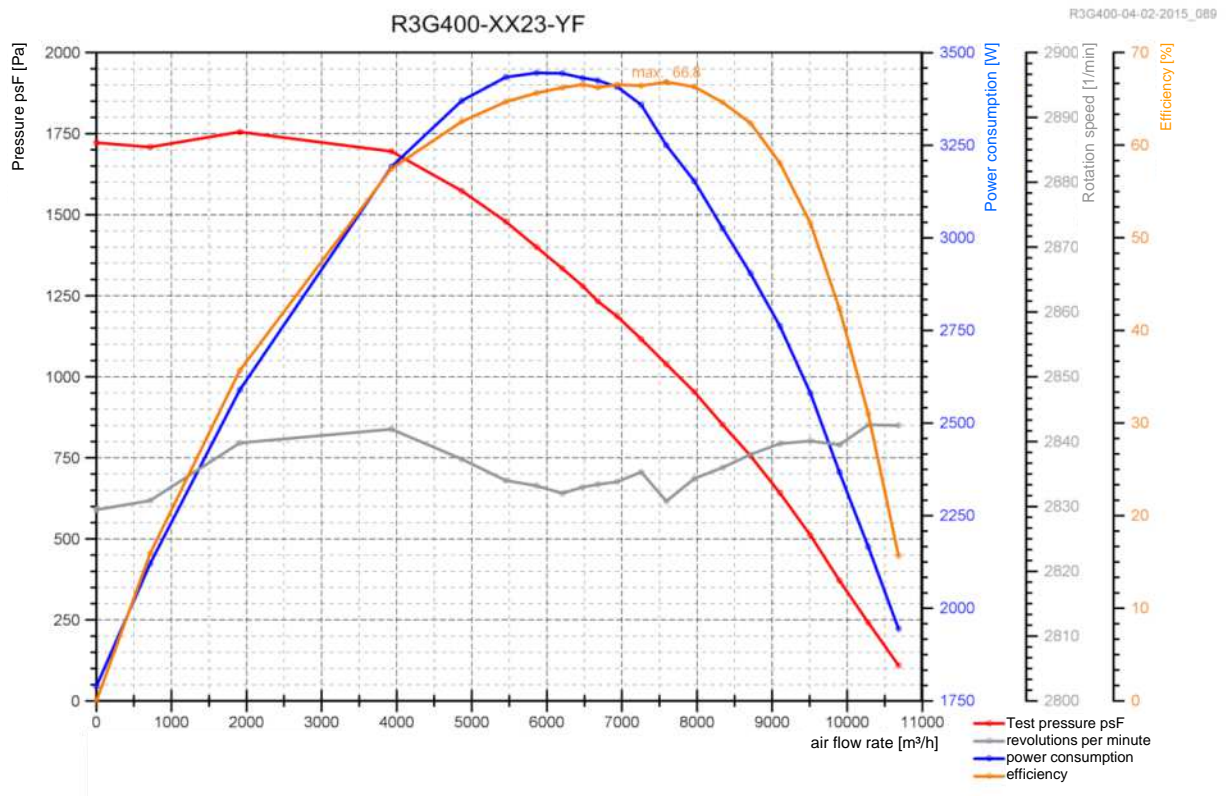


Figure 12: Fan characteristics R3G400-XX23-YF (Sample 1)

The maxima of the efficiency provided in Table 1 are illustrated in Figure 13. It can be observed that the EC fan unit (R3G400-XX23-YF, sample 1) has the largest system efficiency. The difference of the efficiencies at nominal operating conditions of HVAC units is about 3 % to 4 %.

Especially in modern air handling and conditioning units it is possible to adjust the air flow rate according to the demand, leading to part-load ratios of approx. 10 % for many operation hours during one year. The system efficiency of the EC fan unit is approx. 55 % for this particular part-load stage, whereas the PM fan unit with standard shape motor and frequency inverter has system efficiency of approx. 51 %.

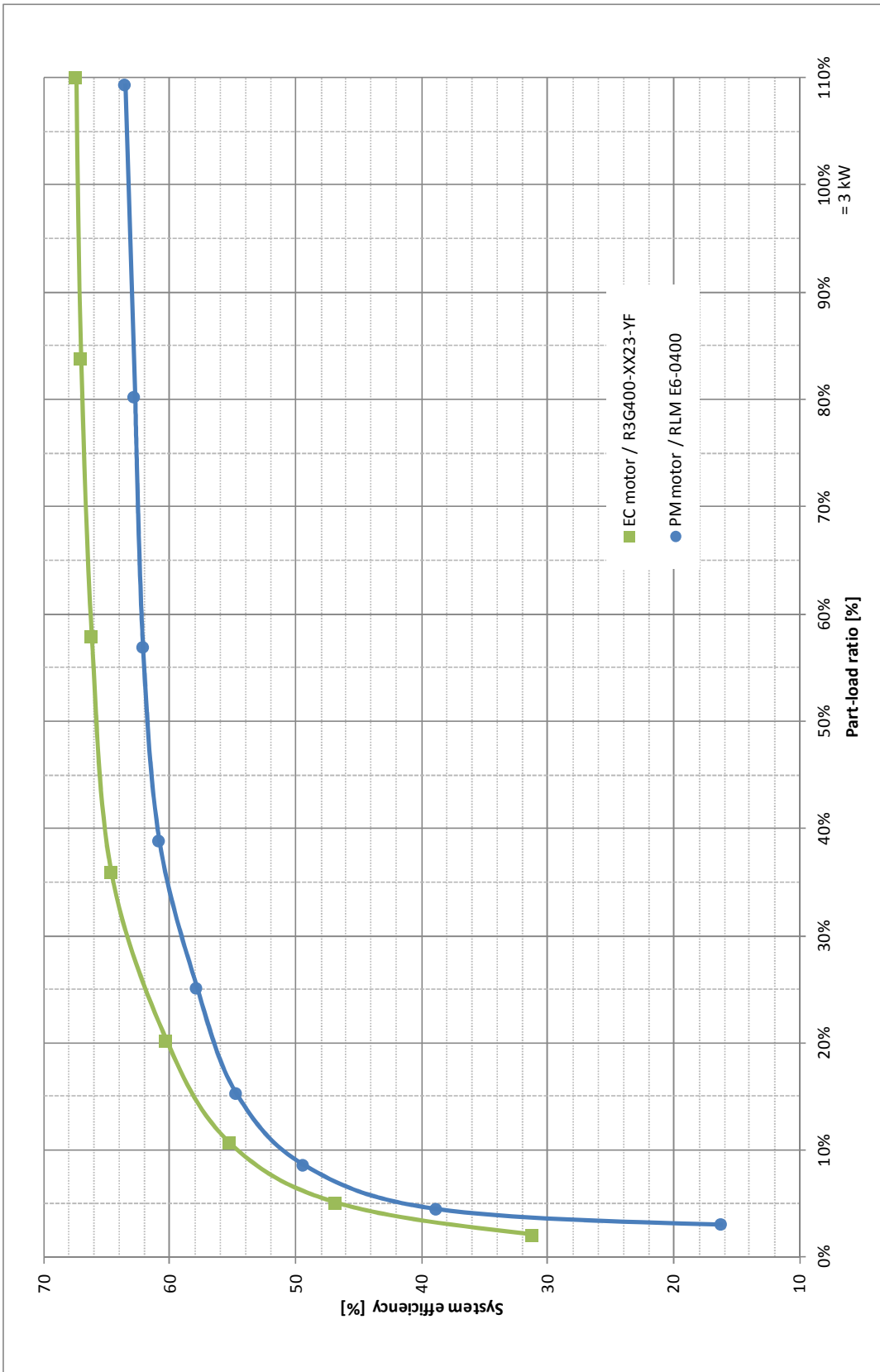


Figure 13: Optimum of the system efficiency depending upon the power demand of the fan driving system

References

- [1] DIN EN ISO 5801:2011
Industrial fans - Performance testing using standardized airways
- [2] Product data sheet of fan units K3G of epm-papst

Table 1: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 10 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
10292	235	1.16	2841	0.07	398.1	3.345	2154	50.0	30.2	10	235
10068	302	1.16	2841	0.09	397.9	3.492	2257	50.0	36.6	10	306
9879	368	1.16	2840	0.07	398.3	3.643	2362	50.0	42.0	10	374
9671	443	1.16	2841	0.07	398.4	3.829	2481	50.0	47.3	10	452
9465	513	1.16	2841	0.06	398.7	3.992	2590	50.0	51.4	10	524
9282	576	1.16	2839	0.07	398.4	4.145	2673	50.0	54.9	10	590
9086	639	1.16	2839	0.10	398.7	4.262	2759	50.0	57.8	10	655
8898	700	1.16	2839	0.06	398.7	4.379	2837	50.0	60.3	10	719
8719	750	1.16	2838	0.06	398.7	4.452	2885	50.0	62.4	10	771
8521	811	1.16	2835	0.09	398.6	4.578	2965	50.0	64.2	10	834
8317	858	1.16	2836	0.07	398.7	4.670	3031	50.0	64.8	10	882
8153	905	1.16	2834	0.09	399.0	4.765	3093	50.0	65.7	10	931
7952	954	1.16	2833	0.13	398.7	4.833	3146	50.0	66.4	10	982
7779	994	1.16	2831	0.08	398.9	4.909	3195	50.0	66.6	10	1023
7623	1045	1.16	2839	0.08	398.9	5.067	3272	50.0	67.0	10	1077
7439	1086	1.16	2837	0.11	399.1	5.104	3299	50.0	67.5	10	1119
7264	1124	1.16	2835	0.07	399.3	5.168	3339	50.0	67.4	10	1158
7078	1163	1.16	2834	0.14	399.2	5.223	3375	50.0	67.2	10	1198
6864	1205	1.16	2832	0.09	399.4	5.282	3395	50.0	67.1	10	1243
6625	1250	1.16	2831	0.10	399.2	5.289	3422	50.0	66.7	10	1289
6393	1295	1.16	2828	0.16	399.2	5.301	3427	50.0	66.6	10	1336
6207	1344	1.16	2840	0.10	399.3	5.356	3470	50.0	66.3	10	1388
5862	1409	1.16	2838	0.11	399.2	5.371	3464	50.0	65.7	10	1455
5449	1483	1.16	2840	0.17	399.5	5.326	3438	50.0	64.7	10	1533
4904	1573	1.16	2842	0.25	399.5	5.208	3369	50.0	63.1	10	1628
4112	1678	1.16	2842	0.36	399.5	4.991	3228	50.0	58.8	10	1738
3008	1745	1.16	2841	0.11	399.4	4.543	2927	50.0	49.4	10	1809
1887	1746	1.16	2840	0.29	399.7	3.973	2574	50.0	35.3	10	1811
1179	1726	1.16	2836	1.01	399.8	3.552	2292	50.0	24.5	10	1790
731	1713	1.16	2835	0.17	399.8	3.310	2133	50.0	16.2	10	1776

Table 2: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 9 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
10307	218	1.17	2835	0.05	397.9	3.290	2114	50.0	28.6	9	217
10136	287	1.16	2840	0.06	398.1	3.463	2232	50.0	35.3	9	289
9928	356	1.16	2839	0.05	398.5	3.617	2339	49.9	41.2	9	362
9732	426	1.16	2839	0.05	398.4	3.808	2444	49.9	46.4	9	435
9533	494	1.16	2839	0.08	398.6	3.950	2548	50.0	50.7	9	505
9132	626	1.16	2837	0.08	398.7	4.214	2719	50.0	57.7	9	642
8944	688	1.16	2836	0.07	398.7	4.305	2788	50.0	60.7	9	707
8748	744	1.16	2834	0.09	398.6	4.415	2848	50.0	62.9	9	765
8560	796	1.16	2833	0.10	398.9	4.514	2921	50.0	64.2	9	819
8376	845	1.16	2832	0.10	399.0	4.625	2994	50.0	65.0	9	869
8181	898	1.16	2830	0.07	398.9	4.719	3061	50.0	66.1	9	924
7983	942	1.16	2830	0.09	399.0	4.806	3117	50.0	66.4	9	970
7814	982	1.16	2828	0.09	398.9	4.925	3161	50.0	66.9	9	1012
7655	1041	1.16	2841	0.09	399.0	5.079	3263	50.0	67.2	9	1072
7486	1076	1.16	2839	0.11	399.1	5.134	3301	50.0	67.2	9	1109
7314	1111	1.16	2837	0.10	398.7	5.159	3330	50.0	67.2	9	1145
7129	1150	1.16	2835	0.09	399.1	5.219	3363	50.0	67.2	9	1186
6936	1191	1.16	2833	0.10	399.0	5.265	3386	50.0	67.2	9	1228
6739	1228	1.16	2832	0.09	399.1	5.279	3411	50.0	66.8	9	1266
6522	1271	1.16	2830	0.11	399.1	5.290	3419	50.0	66.8	9	1311
6351	1305	1.16	2828	0.14	399.0	5.290	3428	50.0	66.6	9	1346
6122	1362	1.16	2838	0.10	399.0	5.377	3467	49.9	66.2	9	1405
5762	1430	1.16	2838	0.11	398.9	5.359	3459	49.9	65.6	9	1477
5384	1495	1.16	2839	0.16	399.2	5.318	3434	49.9	64.6	9	1545
4816	1592	1.16	2842	0.18	399.1	5.190	3361	50.0	62.8	9	1646
4071	1687	1.16	2842	0.27	399.4	4.960	3210	50.0	58.9	9	1746
2993	1746	1.16	2839	0.10	399.3	4.522	2919	50.0	49.3	9	1809
1955	1754	1.16	2838	0.16	399.6	4.030	2593	50.0	36.4	9	1818
1173	1728	1.16	2836	0.90	399.7	3.560	2289	50.0	24.4	9	1791
723	1710	1.16	2832	0.14	399.9	3.307	2120	50.0	16.1	9	1771

Table 3: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 8 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
9637	115	1.17	2589	0.06	398.5	2.403	1533	50.0	19.1	8	112
9232	242	1.16	2594	0.08	398.6	2.698	1725	50.0	35.1	8	243
9027	310	1.16	2594	0.08	398.7	2.830	1825	50.0	41.8	8	314
8829	373	1.16	2595	0.07	398.8	2.981	1912	50.0	47.2	8	380
8631	434	1.16	2595	0.07	399.0	3.105	2003	50.0	51.3	8	443
8423	501	1.16	2594	0.11	399.2	3.218	2081	49.9	55.7	8	512
8211	564	1.16	2593	0.11	399.0	3.360	2164	50.0	58.8	8	577
7980	625	1.16	2593	0.07	398.9	3.447	2219	50.0	61.8	8	640
7734	688	1.16	2591	0.06	398.8	3.549	2290	50.0	64.0	8	705
7460	750	1.16	2590	0.08	399.1	3.655	2368	50.0	65.1	8	770
7205	806	1.16	2587	0.14	399.1	3.733	2416	50.0	66.2	8	828
6916	867	1.16	2584	0.11	399.0	3.832	2472	50.0	66.9	8	891
6651	920	1.16	2582	0.10	399.0	3.893	2514	50.0	67.1	8	946
6374	971	1.16	2581	0.07	399.3	3.959	2553	50.0	66.8	8	999
6070	1032	1.16	2579	0.14	399.1	4.001	2585	50.0	66.8	8	1062
5731	1092	1.16	2579	0.12	399.3	4.022	2602	50.0	66.3	8	1125
5374	1155	1.16	2579	0.17	399.3	4.025	2604	50.0	65.8	8	1191
4963	1221	1.16	2579	0.15	399.3	3.996	2588	50.0	64.6	8	1259
4548	1287	1.16	2580	0.18	399.3	3.947	2547	50.0	63.4	8	1328
4047	1353	1.16	2582	0.27	399.1	3.852	2478	50.0	61.0	8	1398
3406	1418	1.16	2587	0.15	399.5	3.695	2377	50.0	56.0	8	1466
2706	1459	1.16	2592	0.11	399.7	3.472	2230	50.0	48.8	8	1509
2075	1471	1.16	2595	0.13	399.8	3.252	2075	50.0	40.6	8	1522
1459	1461	1.16	2596	0.58	400.0	3.005	1907	50.0	30.8	8	1511
1163	1452	1.16	2594	0.29	399.9	2.857	1809	50.0	25.8	8	1501
900	1444	1.16	2595	0.15	400.1	2.731	1736	50.0	20.7	8	1493
566	1437	1.16	2594	0.22	400.3	2.561	1616	49.9	13.9	8	1485
298	1425	1.16	2590	0.54	400.2	2.379	1489	50.0	7.9	8	1473

Table 4: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 7 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
8044	168	1.17	2246	0.08	399.7	1.835	1137	50.0	32.3	7	169
7836	228	1.17	2248	0.07	399.5	1.934	1212	50.0	40.3	7	230
7620	287	1.17	2251	0.05	399.8	2.050	1284	50.0	46.7	7	291
7408	346	1.17	2251	0.13	399.7	2.149	1354	50.0	52.0	7	352
7184	405	1.17	2252	0.10	399.9	2.244	1418	50.0	56.5	7	413
6924	466	1.17	2254	0.11	400.1	2.339	1481	50.0	60.0	7	476
6656	532	1.17	2253	0.12	399.9	2.420	1536	50.1	63.6	7	544
6375	590	1.17	2253	0.09	399.6	2.532	1597	50.0	64.9	7	603
6052	652	1.17	2253	0.12	399.7	2.613	1654	50.0	65.8	7	668
5628	727	1.17	2252	0.17	399.9	2.689	1706	50.0	66.2	7	746
5325	782	1.17	2251	0.15	399.8	2.742	1735	50.0	66.3	7	802
4967	838	1.17	2252	0.16	400.0	2.761	1750	50.0	65.7	7	861
4559	899	1.17	2251	0.21	399.8	2.758	1746	50.0	64.8	7	924
4162	952	1.17	2251	0.25	400.0	2.722	1725	50.0	63.5	7	979
3682	1015	1.17	2251	0.30	399.9	2.663	1685	50.0	61.3	7	1045
3083	1063	1.16	2251	0.10	399.8	2.568	1606	50.0	56.4	7	1095
2453	1104	1.16	2251	0.10	399.9	2.417	1504	50.0	49.8	7	1137
1863	1110	1.16	2251	0.19	400.1	2.248	1395	50.0	41.0	7	1143
1405	1100	1.17	2249	0.24	400.1	2.110	1301	50.0	32.8	7	1133
1068	1090	1.17	2246	0.17	400.1	2.008	1228	50.0	26.2	7	1123
794	1080	1.17	2243	0.20	400.1	1.903	1160	50.0	20.4	7	1112
498	1077	1.17	2240	0.17	400.2	1.783	1076	50.0	13.8	7	1109
256	1068	1.17	2239	0.51	400.4	1.648	993	50.0	7.6	7	1099

Table 5: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 6 V

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air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
6857	127	1.17	1919	0.11	400.2	1.297	743	50.0	31.7	6	127
6676	164	1.17	1919	0.13	400.1	1.325	779	50.0	38.4	6	165
6489	211	1.17	1920	0.12	400.0	1.410	826	50.0	45.4	6	213
6309	252	1.17	1920	0.12	400.1	1.466	867	50.0	50.4	6	256
6088	301	1.17	1921	0.09	400.4	1.549	915	50.0	55.1	6	306
5834	350	1.17	1920	0.13	400.0	1.591	949	50.0	59.3	6	356
5572	396	1.17	1917	0.12	399.9	1.644	984	50.0	61.8	6	403
5261	445	1.17	1912	0.18	400.0	1.685	1019	50.0	63.4	6	454
4431	569	1.17	1905	0.24	400.2	1.766	1077	50.0	64.7	6	582
3930	633	1.17	1904	0.15	400.3	1.776	1083	50.0	63.4	6	647
3409	694	1.17	1906	0.09	400.2	1.765	1069	50.0	61.2	6	711
3118	725	1.17	1908	0.13	400.2	1.728	1051	50.0	59.5	6	743
2687	765	1.17	1912	0.13	400.2	1.678	1015	50.0	56.0	6	785
2249	794	1.17	1916	0.13	400.4	1.634	973	50.0	50.7	6	814
1889	805	1.17	1919	0.13	400.4	1.596	933	50.0	45.1	6	826
1602	809	1.17	1919	0.21	400.5	1.541	893	50.0	40.2	6	830
1310	803	1.17	1917	0.38	400.3	1.476	852	50.0	34.2	6	824
1150	800	1.17	1916	0.45	400.4	1.446	828	50.0	30.7	6	820
926	798	1.17	1917	0.23	400.6	1.383	794	50.0	25.7	6	818
704	792	1.17	1916	0.20	400.6	1.322	756	50.0	20.4	6	813
532	792	1.17	1915	0.29	400.6	1.319	722	50.0	16.1	6	812
348	790	1.17	1916	0.45	400.6	1.265	684	50.0	11.1	6	809

Table 6: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 5 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
5249	133	1.18	1550	0.12	400.2	0.896	467	50.0	41.1	5	134
5019	175	1.18	1548	0.15	400.6	0.950	500	50.0	48.4	5	177
4785	213	1.18	1546	0.14	400.4	0.995	527	50.0	53.3	5	216
4536	250	1.17	1546	0.25	400.7	1.038	550	50.0	57.0	5	254
4298	286	1.17	1545	0.26	400.6	1.076	573	50.0	59.4	5	291
4004	322	1.17	1543	0.16	400.8	1.105	592	50.0	60.2	5	327
3714	355	1.17	1542	0.25	400.5	1.118	605	50.0	60.3	5	362
3434	387	1.17	1543	0.40	400.6	1.138	613	50.0	60.0	5	394
3152	412	1.17	1541	0.10	400.5	1.129	611	50.0	58.9	5	421
2853	440	1.17	1541	0.12	400.5	1.118	605	50.0	57.4	5	449
2565	464	1.17	1540	0.10	400.6	1.092	592	50.0	55.7	5	474
2244	494	1.17	1543	0.12	400.6	1.084	577	50.0	53.2	5	505
1903	509	1.17	1542	0.11	400.8	1.038	553	50.0	48.6	5	520
1571	522	1.17	1547	0.19	400.8	1.010	530	50.0	42.8	5	533
1362	525	1.17	1547	0.51	400.7	0.977	512	50.0	38.7	5	536
1102	523	1.17	1547	0.33	400.5	0.930	488	50.0	32.7	5	534
991	524	1.17	1548	0.14	400.7	0.912	478	50.0	30.1	5	535
766	521	1.17	1549	0.16	400.7	0.879	457	50.0	24.2	5	533
577	522	1.17	1552	0.12	400.6	0.852	438	50.0	19.0	5	533
423	521	1.17	1553	0.19	400.8	0.819	418	50.0	14.6	5	532

Table 7: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 4 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
4236	73	1.18	1228	0.36	400.9	0.545	251	50.0	33.8	4	74
4042	99	1.18	1225	0.32	401.0	0.571	266	50.0	41.2	4	99
3852	124	1.18	1223	0.36	401.2	0.592	279	50.0	47.0	4	125
3662	146	1.18	1221	0.30	401.0	0.607	290	50.0	50.9	4	148
3440	171	1.18	1222	0.52	401.1	0.634	303	50.0	53.7	4	174
3221	193	1.18	1221	0.12	400.9	0.648	313	50.0	54.8	4	195
2999	213	1.18	1219	0.07	401.0	0.653	320	50.0	55.3	4	216
2753	235	1.18	1217	0.15	400.9	0.666	324	50.0	55.2	4	239
2460	257	1.18	1214	0.10	401.1	0.658	323	50.0	54.2	4	262
2112	284	1.18	1217	0.17	400.8	0.653	319	50.0	52.1	4	289
1667	311	1.18	1218	0.20	400.8	0.621	303	50.0	47.4	4	317
1224	323	1.18	1220	0.34	401.1	0.592	284	50.0	38.6	4	329
705	325	1.18	1226	0.12	401.1	0.557	258	50.0	24.6	4	331
336	325	1.18	1230	0.52	401.2	0.513	233	50.0	13.0	4	331

Table 8: Measured values of the EC fan unit R3G400-XX23-YF with a control signal of 3 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
3111	34	1.18	901	0.11	401.2	0.322	120	50.0	24.1	3	34
3039	43	1.18	901	0.12	401.0	0.333	124	50.0	29.0	3	43
2949	52	1.18	898	0.09	401.3	0.340	127	50.0	32.8	3	52
2867	60	1.18	899	0.07	401.3	0.347	131	50.0	36.4	3	61
2798	67	1.18	898	0.16	401.2	0.349	133	50.0	38.6	3	67
2706	75	1.18	897	0.08	400.8	0.352	136	50.0	41.2	3	76
2635	81	1.18	896	0.13	401.0	0.355	139	50.0	42.7	3	82
2555	87	1.18	893	0.06	401.2	0.356	140	50.0	43.8	3	88
2473	94	1.18	892	0.12	401.2	0.359	142	50.0	45.0	3	95
2398	100	1.18	893	0.12	401.3	0.361	145	50.0	45.6	3	101
2320	105	1.18	892	0.12	401.2	0.365	147	50.0	46.1	3	106
2232	112	1.18	893	0.19	401.2	0.375	149	50.0	46.4	3	113
2152	118	1.18	894	0.12	401.2	0.377	150	50.0	46.9	3	120
2062	124	1.18	893	0.12	400.9	0.376	151	50.0	46.7	3	125
1969	129	1.18	893	0.14	401.2	0.378	152	50.0	46.5	3	131
1884	134	1.18	891	0.13	401.1	0.377	151	50.0	46.3	3	136
1766	140	1.18	889	0.25	401.1	0.371	150	50.0	45.7	3	142
1615	149	1.18	892	0.20	401.2	0.372	150	50.0	44.6	3	151
1410	160	1.18	893	0.28	401.3	0.364	147	50.0	42.5	3	162
1133	170	1.18	894	0.64	401.3	0.357	141	50.1	37.7	3	172
835	175	1.18	896	0.08	401.2	0.348	134	50.1	30.3	3	178
500	175	1.18	899	0.16	401.4	0.331	124	50.0	19.5	3	178
238	175	1.18	902	0.52	401.0	0.315	114	50.0	10.1	3	178

Table 9: Measured values of the PM fan unit RLM E6-0400 with a control signal of 10 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
8760.2	326	1.1718	2850	0.09	398.7	3.961	2460	50.0	31.7	10	329
8582.1	396	1.1712	2850	0.07	398.7	4.088	2537	50.0	36.7	10	400
8394.7	466	1.1709	2850	0.08	398.8	4.203	2613	50.0	41.1	10	473
8216.5	541	1.1706	2850	0.07	398.9	4.338	2679	50.0	45.6	10	550
8040.5	612	1.1706	2850	0.10	399.1	4.409	2742	50.0	49.4	10	623
7873.2	683	1.1702	2850	0.08	398.7	4.534	2816	50.0	52.6	10	696
7715.6	752	1.1698	2850	0.12	398.9	4.631	2892	50.0	55.2	10	767
7549.2	812	1.1696	2850	0.08	399.0	4.754	2957	50.0	57.1	10	829
7400.5	866	1.1693	2850	0.10	399.1	4.858	3017	50.0	58.5	10	885
7235.3	924	1.1692	2850	0.13	399.0	4.941	3074	50.0	59.9	10	945
7082.5	977	1.1692	2850	0.08	399.3	4.998	3121	50.0	61.1	10	999
6918.8	1023	1.169	2850	0.15	399.3	5.066	3160	50.0	61.7	10	1047
6745.8	1071	1.1689	2850	0.16	399.1	5.124	3200	50.0	62.2	10	1097
6564.5	1118	1.1686	2850	0.09	399.1	5.175	3223	50.0	62.8	10	1145
6361.4	1172	1.1683	2850	0.19	399.1	5.266	3248	50.0	63.3	10	1202
6122.5	1226	1.1681	2850	0.08	399.2	5.215	3264	50.0	63.4	10	1257
5952.6	1271	1.1678	2850	0.14	399.4	5.254	3279	50.0	63.6	10	1304
5630.9	1337	1.1673	2850	0.16	399.4	5.268	3284	50.0	63.2	10	1372
5236.8	1420	1.1664	2850	0.16	399.5	5.251	3273	50.0	62.6	10	1459
4708.6	1518	1.1653	2850	0.22	399.2	5.166	3223	50.0	61.1	10	1562
3999.7	1623	1.1642	2850	0.36	399.4	4.992	3106	50.0	57.6	10	1672
2937.4	1715	1.1632	2850	0.16	399.5	4.548	2798	50.0	49.6	10	1769
1947.9	1733	1.163	2850	0.19	400.0	3.977	2398	50.0	38.8	10	1788
1231.6	1743	1.1629	2850	2.43	400.2	3.550	2078	50.0	28.5	10	1798
706.36	1750	1.1628	2850	0.23	400.5	3.228	1835	50.0	18.6	10	1806

Table 10: Measured values of the PM fan unit RLM E6-0400 with a control signal of 9 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
8040.9	209	1.1712	2568	0.07	399.4	3.061	1769	50.0	25.9	9	210
7843.6	278	1.1707	2568	0.08	399.5	3.173	1838	50.0	32.4	9	281
7667	339	1.1703	2568	0.07	399.5	3.255	1897	50.0	37.6	9	344
7479.6	403	1.1701	2568	0.07	400.0	3.311	1955	50.0	42.4	9	410
7296.9	466	1.1698	2568	0.11	399.9	3.401	2005	50.0	46.7	9	474
7136.4	533	1.1702	2568	0.11	399.8	3.484	2062	50.0	50.8	9	543
6801	659	1.1697	2568	0.12	400.1	3.643	2183	50.0	56.6	9	673
6634.6	704	1.1693	2568	0.09	399.9	3.717	2226	50.0	57.9	9	720
6470.1	760	1.1689	2568	0.09	399.8	3.795	2275	50.0	59.6	9	778
6295.5	807	1.1686	2568	0.12	399.9	3.880	2317	50.0	60.5	9	826
6107.2	854	1.1684	2568	0.10	399.9	3.929	2349	50.0	61.3	9	875
5922.7	901	1.1683	2568	0.15	399.7	3.928	2370	50.0	62.1	9	923
5663.8	955	1.168	2568	0.15	399.9	3.912	2389	50.0	62.5	9	979
5428.6	1010	1.1675	2568	0.18	399.7	3.938	2406	50.0	62.9	9	1036
5118.1	1073	1.1671	2568	0.24	399.8	3.996	2415	50.0	62.7	9	1101
4788.9	1132	1.1667	2568	0.19	399.9	4.007	2409	50.0	62.1	9	1163
4303.6	1212	1.1659	2568	0.16	399.8	3.947	2381	50.0	60.5	9	1246
3646.3	1308	1.1649	2568	0.38	400.1	3.833	2290	50.0	57.5	9	1347
2692.4	1385	1.1642	2568	0.11	400.3	3.549	2083	50.0	49.4	9	1427
1775.2	1408	1.1638	2568	0.69	400.5	3.194	1786	50.0	38.6	9	1452
1139.8	1414	1.1639	2568	0.45	400.8	2.874	1557	50.0	28.6	9	1458
662.86	1417	1.1639	2568	0.17	400.9	2.574	1373	50.0	18.9	9	1461
0	1448	1.1642	2568	NaN	401.2	2.162	1143	50.0	0.0	9	1492

Table 11: Measured values of the PM fan unit RLM E6-0400 with a control signal of 8 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
6984.5	201	1.1718	2282	0.13	400.1	2.484	1298	50.1	29.5	8	202
6727.5	280	1.1711	2282	0.14	400.1	2.578	1362	50.1	37.9	8	284
6493.3	350	1.1705	2282	0.09	400.4	2.679	1417	50.1	44.2	8	357
6260.6	432	1.1699	2282	0.12	400.2	2.774	1480	50.1	50.3	8	440
6024.1	511	1.1699	2282	0.09	400.2	2.843	1545	50.0	55.0	8	522
5758.4	590	1.1693	2282	0.20	400.6	2.906	1606	50.0	58.3	8	603
5490.8	659	1.1693	2282	0.15	400.5	2.982	1655	50.0	60.4	8	674
5175.6	724	1.169	2282	0.15	400.3	3.028	1687	50.0	61.3	8	741
4842.3	793	1.1686	2282	0.24	400.3	3.037	1706	50.0	62.2	8	813
4459.4	856	1.1683	2282	0.30	400.1	3.013	1714	50.0	61.5	8	878
4051.5	926	1.1678	2282	0.29	400.6	2.974	1702	50.0	60.9	8	951
3604.7	993	1.1673	2282	0.32	400.4	2.927	1671	50.0	59.2	8	1020
3052.1	1052	1.1668	2282	0.10	400.6	2.875	1607	50.0	55.2	8	1081
2421.2	1097	1.1663	2282	0.16	400.7	2.706	1489	50.0	49.3	8	1128
1847.9	1112	1.1663	2282	0.18	400.9	2.507	1350	50.0	42.1	8	1144
1402.5	1116	1.1663	2282	0.24	401.0	2.330	1225	50.0	35.3	8	1148
1102.7	1118	1.1663	2282	0.82	401.1	2.161	1140	50.0	29.9	8	1150
802.11	1117	1.1664	2282	0.14	401.4	2.035	1053	50.0	23.5	8	1150
501	1129	1.1664	2282	0.37	401.2	1.888	962	50.0	16.2	8	1161
259.73	1136	1.1666	2282	0.67	400.9	1.756	893	50.0	9.1	8	1168

Table 12: Measured values of the PM fan unit RLM E6-0400 with a control signal of 7 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
6038.2	167	1.1741	1995	0.16	400.6	1.753	902	50.0	30.7	7	169
5775	241	1.1735	1995	0.15	400.5	1.832	953	50.0	40.2	7	244
5492.3	324	1.1729	1995	0.13	400.1	1.908	1007	50.0	48.7	7	329
5124.8	421	1.172	1995	0.32	400.1	2.046	1079	50.0	55.2	7	430
4827.9	495	1.1716	1995	0.16	400.3	2.133	1122	50.0	58.9	7	506
4505.5	551	1.1713	1995	0.27	400.7	2.180	1151	50.0	59.6	7	563
4094.4	626	1.1706	1995	0.20	401.0	2.178	1165	50.0	60.9	7	641
3704.2	684	1.17	1995	0.45	400.9	2.188	1163	50.0	60.2	7	701
3287.7	739	1.1694	1995	0.11	400.7	2.171	1149	50.0	58.4	7	757
2796.7	789	1.1689	1995	0.18	400.9	2.108	1111	50.0	55.0	7	810
2203.7	830	1.1685	1995	0.12	400.7	1.979	1034	50.0	49.0	7	852
1706.6	849	1.1683	1995	0.19	400.8	1.823	946	50.0	42.4	7	872
1329.7	853	1.1683	1995	0.29	400.8	1.690	865	50.0	36.2	7	876
1049.4	853	1.1685	1995	0.23	401.1	1.569	804	50.0	30.8	7	876
730.25	861	1.1685	1995	0.18	401.0	1.430	733	50.0	23.7	7	884
448.72	862	1.1687	1995	0.42	401.0	1.331	670	50.0	16.0	7	885

Table 13: Measured values of the PM fan unit RLM E6-0400 with a control signal of 6 V

air flow rate	test pressure psF	density (test chamber)	fan rotation speed	standard deviation air flow	voltage	electrical current	electrical power	mains frequency	efficiency	control signal 0-10 V	dpfa at rho=1.2
m ³ /h	Pa	kg/m ³	U/min	%	V	A	W	Hz	%	V	Pa
5094.3	135	1.1748	1708	0.23	401.0	1.198	599	50.0	31.6	6	137
4802.9	205	1.1741	1708	0.12	401.0	1.271	637	50.0	42.7	6	209
4495.2	285	1.1733	1708	0.12	401.0	1.364	685	50.0	51.7	6	290
4063.8	368	1.1726	1708	0.28	401.2	1.442	734	50.0	56.4	6	376
3622.1	435	1.172	1708	0.20	401.0	1.467	753	50.0	57.9	6	445
3131	500	1.1715	1708	0.30	401.1	1.436	753	50.0	57.6	6	512
2828	537	1.1714	1708	0.11	401.3	1.461	745	50.0	56.4	6	549
2458.5	573	1.1712	1708	0.11	401.2	1.431	726	50.0	53.8	6	587
2075.3	604	1.171	1708	0.15	401.4	1.370	693	50.0	50.1	6	618
1750.9	614	1.171	1708	0.11	401.4	1.297	657	50.0	45.4	6	629
1459.9	624	1.171	1708	0.50	401.3	1.241	618	50.0	40.8	6	639
1242.7	622	1.171	1708	0.30	401.3	1.185	584	50.0	36.7	6	638
1084.4	621	1.1711	1708	0.14	401.4	1.121	558	50.0	33.4	6	636
835.64	630	1.171	1708	0.20	401.1	1.046	519	50.0	28.1	6	645
646.52	630	1.1711	1708	0.15	401.2	0.989	489	50.0	23.1	6	646
462.98	630	1.1713	1708	0.25	401.4	0.934	459	50.0	17.6	6	646
187.62	639	1.1718	1708	1.41	401.7	0.876	415	50.0	8.0	6	654