Big Dutchman International GmbH

Heat Exchanger Earny Type 40.000

Efficiency of heat recovery under practical conditions

DLG Test Report 6140F

Revision 1: Amendment(s) see page 10

FOKUS TEST
09/13 Efficiency of heat recovery under practical conditions

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Assessment – summary

The DLG Focus Test "Efficiency of heat recovery" of the Big Dutchman air-air heat exchanger Earny Type 40.000 for use in broiler houses was conducted as a practical test in accordance with DIN EN 308, delivering the following results:

Test result	Evaluation*
Efficiency of heat recovery	
Average temperature-transfer efficiency: 57 % at ΔT = 12,6 °C	+ +
Heat output	
Average output under winter conditions: 23.8 kW (see Operating conditions, p. 4)	N/A

DLG evaluation standard for recuperative heat exchangers in practical agricultural use:					
Assessment	+ +	+	○	–	– –
Temperature-transfer efficiency [%]	> 50	> 40 to 50	> 30 to 40	> 20 to 30	< 20

* Evaluation range: + + / + / ○ / – / – – (○ = standard) / N/A = Not Assessed

Main technical data (manufacturer's data)

Construction

The Big Dutchman heat exchanger Earny Type 40.000 is used to recover heat from the return air in broiler houses.

Experience shows that the heat exchanger has a positive influence on the broiler house's climate and on the litter quality. This reduces emissions of ammonia and odours. The Earny Type 40.000 works as a recuperative[1] cross flow heat exchanger (Fig. 2). This heat exchanger therefore falls under Category I. This means that warm poultry-house air ① and cold ambient air ② are fed simultaneously through exchanger bundles and that the air flows do not come into contact with one another during this process; only heat is exchanged. The clean ambient air is separated from the contaminated poultry-house return air in a hygienic manner. Only clean ambient air is fed back into the poultry house ③. A filter unit ④ ensures that only clean return air enters the heat exchanger. The automatic cleaning ⑤ of the filter cartridges is a prerequisite for ensuring that there is no drop in the heat exchanger's performance during the fattening cycle. The heat exchanger's exhaust air ⑦ is therefore almost completely cleared of dust and particulate-matter emissions. The exchanger element ⑥ is made of coated aluminium and has a ribbed structure in order to ensure a high rate of heat transfer. Axial fans convey the inlet and return air.

Planning data

Air flow

20,000 m³/h for use in a fattening house with approx. 40,000 birds

Heat-recovery performance

170 kW (when $\dot{V}_{return}$ = 13,100 m³/h, T_{return} = 30 °C, Φ_{return} = 60 %, $\dot{V}_{inlet}$ = 18,600 m³/h, T_{inlet} = -10 °C, Φ_{inlet} = 60 %)

Dimensions

Length / width / height[2]	5,200 mm / 2,300 mm / 2,300 mm

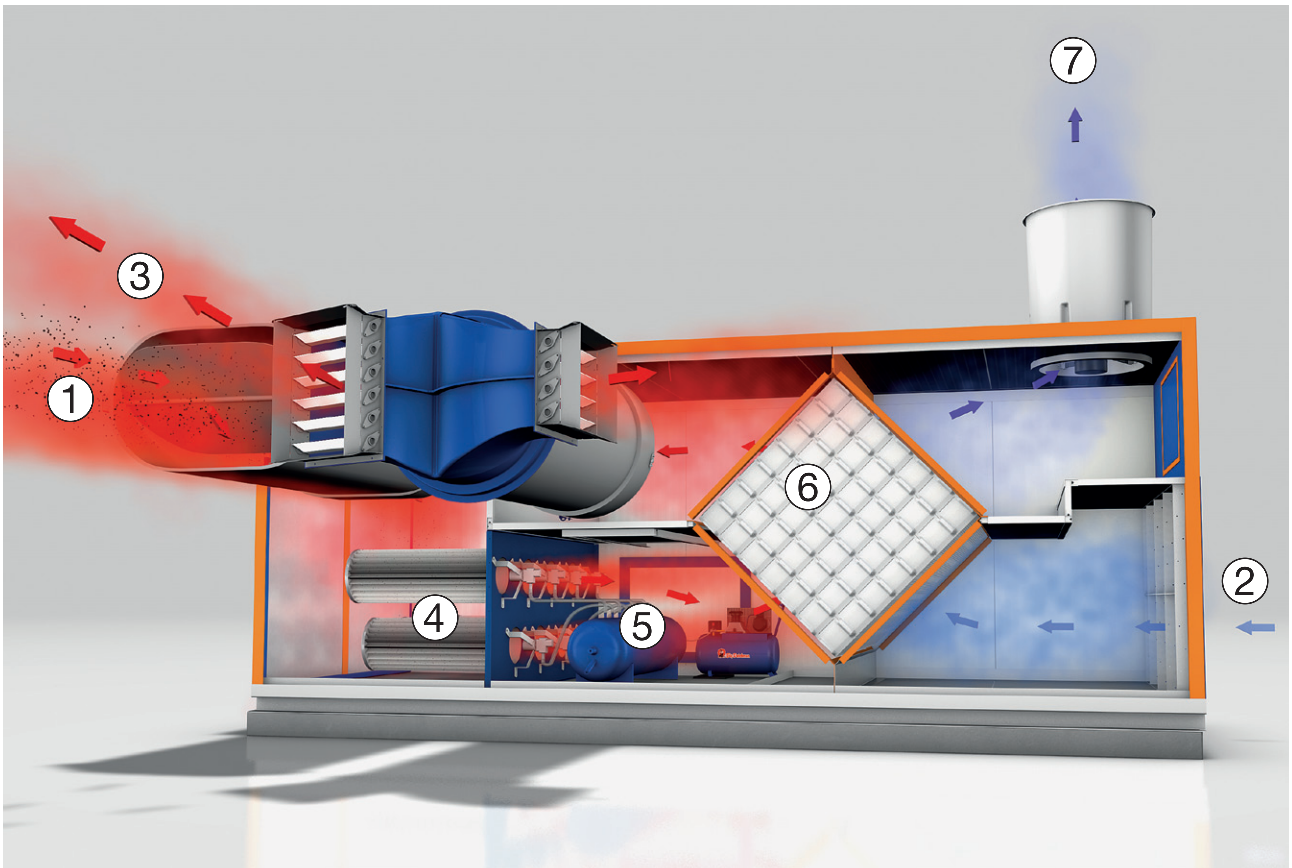


Figure 2:
Functional principle

1 The term recuperation is generally used in relation to technical processes for energy recovery.
In recuperative heat exchangers (cross- and counter-flow), exhaust and ambient air pass alongside one another without exchange of air and/or moisture.

2 Value for height of heat exchanger without diffusor

Test results

The tested Big Dutchman heat exchanger Earny Type 40.000 worked reliably throughout the test period.

Measurement in a broiler house

The Big Dutchman heat exchanger Earny Type 40.000 was tested on an existing broiler house with a floor area of 1800 m². Measurements were recorded over three fattening periods from 10 December 2012 to 29 April 2013.

In the tested winter months, the Big Dutchman heat exchanger Earny Type 40.000 achieved an average temperature-transfer efficiency of 57 % (Fig. 4, page 4). This means that 57 % of the maximum achievable inlet-air temperature was achieved. The efficiency of heat recovery is therefore better than the current definition of a standard level of > 30 % to 40 %. In addition, the temperature-transfer efficiency varied only slightly, by ± 3.5 %. The heat exchanger raised the temperature of ambient air by 12.6 °C on average. However, this temperature increase depends very strongly on the weather conditions: the greater the temperature difference between the poultry-house air and the outside air, the greater the heating effect, and vice versa. Using the heat exchanger also avoids passing on and strongly attenuates the sometimes very large variations in the ambient-air temperature, which varies with the outside temperature.

If the poultry-house ventilation system is operated in combination with a heat exchanger, the thermal energy gained from heat recovery is offset by an increased demand for electrical energy on the part of the fans. This arises due to the additional pressure losses in the heat exchanger that must be overcome. This increased consumption of electrical energy is many times lower than the recovered thermal energy. The ratio is approximately 1:20. This means that for one kilowatt-hour of electrical energy (electricity), approx. 20 kilowatt-hours of thermal energy (heat) can be recovered.

Figure 5 (page 7) and Figure 6 (page 8) show the variations in temperature-transfer efficiency, inlet-air temperature increase, ambient-air temperature, heat output and inlet-air volume flow rate. Because of the large volume of data, not all data points are visualised. Occasionally, measurements were taken that exceed the scale.

Efficiency of heat recovery

The temperature-transfer efficiency represents a key quality parameter for evaluating a heat-recovery system. Overview 2 (page 5) provides an explanation of correlations and calculations for heat exchangers.

The following results relate exclusively to operating conditions.

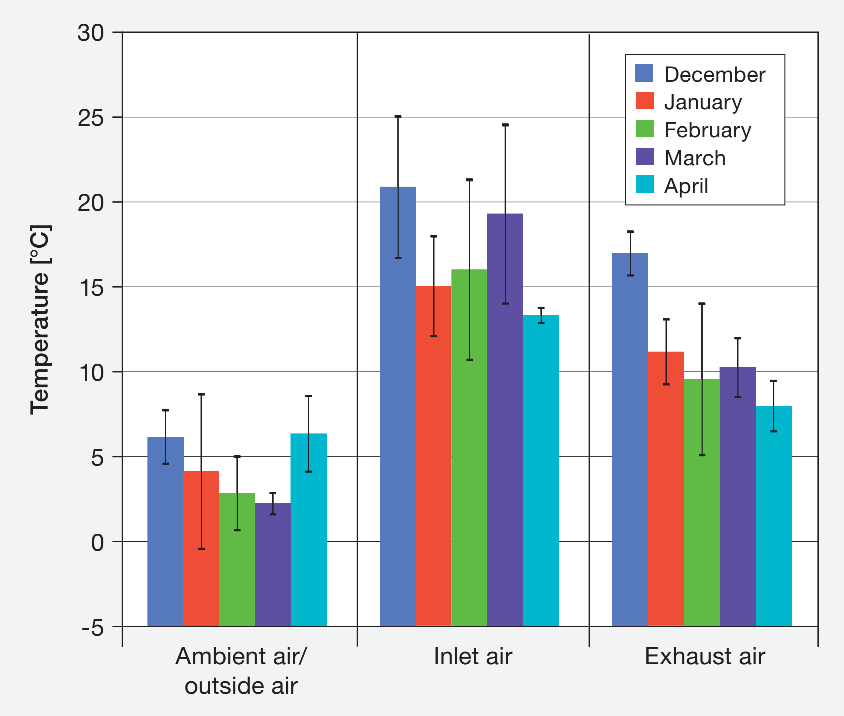


Figure 3:
Bar chart of temperatures showing measured range (standard deviation)

Table of supplementary data for Figure 3:

Average temperature [°C]			
	Ambient air/outside air	Inlet air	Exhaust air
December	6.1	20.9	17.0
January	4.1	15.1	11.2
February	2.8	16.0	9.5
March	2.2	19.3	10.3
April	6.5	13.9	8.0

Minimum and maximum values of ambient-air temperature [°C]					
	December	January	February	March	April
Minimum	-2	-7	-5	-4	-3
Maximum	12	13	10	16	19

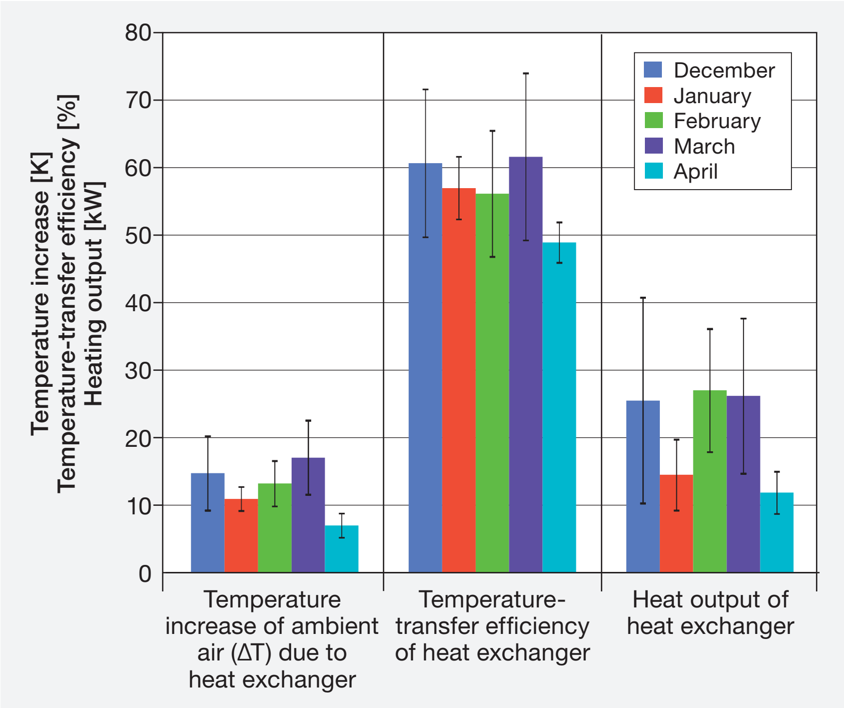


Figure 4:
Bar chart of performance parameters showing measured range (standard deviation)

Operating mode (according to manufacturer's information)

The heat exchanger was controlled by the AMACS climate-control computer during the testing phase. The air volume flow rate passing through the heat exchanger was regulated by the minimum ventilation.

Starting with a minimum ventilation or with the additional humidity control, the heat exchanger's ventilation requirement increased as the number of days of fattening increased (see Fig. 6). After 14 to 18 days of fattening, in order to achieve energy-optimised operation, the heat exchanger is automatically switched to a stand-by mode in which the exchanger operated at a reduced level of ventilation.

Table of supplementary data for Figure 4:*

	Temperature increase of ambient air (ΔT) due to heat exchanger [K]	Temperature-transfer efficiency of heat exchanger [%]	Heat output achieved by heat exchanger [kW]
December	14.8 ± 5.5	53 ± 3	29.2 ± 7.8
January	11.0 ± 1.8	59 ± 5	15.7 ± 6.6
February	13.2 ± 3.4	60 ± 3	31.7 ± 11.4
March	17.1 ± 5.5	54 ± 2	32.4 ± 9.9
April	7.0 ± 1.8	56 ± 6	13.1 ± 7.2
Mean	12.6 ± 3.6	57 ± 4	23.8 ± 8.9

Overview 1:
Operating states during the measurement period

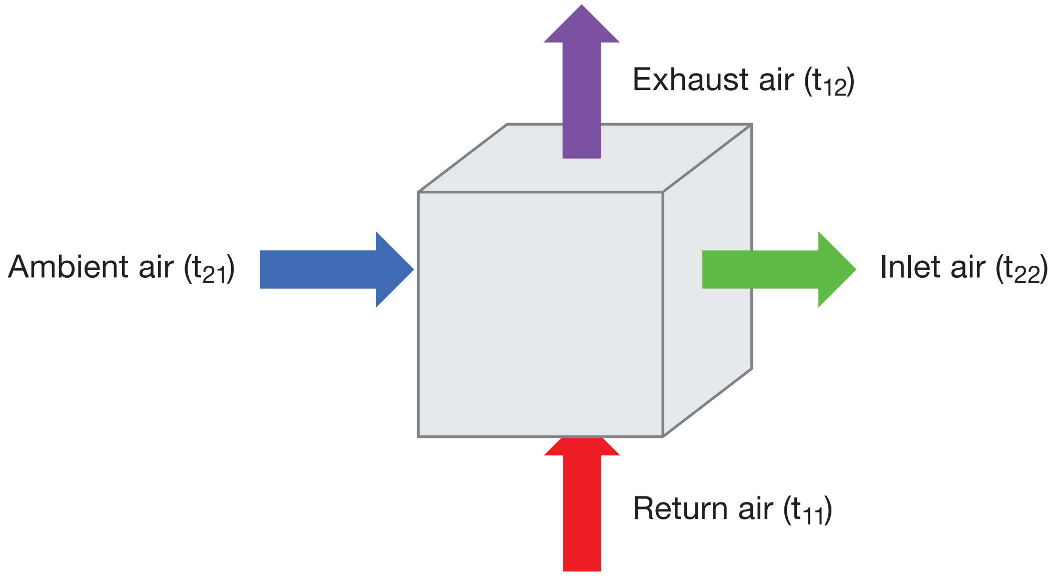
Condensation arising [kg/h] from December to March	
December	12.3 ± 4.3
January	15.5 ± 5.2
February	8.4 ± 1.4
March	11.6 ± 4.2
Mean	12.0 ± 3.8

Mean air volume flow rates for the heat exchanger over the entire measurement period	
Inlet air [m^3/h]	5,008 ± 2,375
Return air [m^3/h]	5,025 ± 2,036

Temperature [°C] of the return air over the entire measurement period
26.2 ± 5.2

* Explanation of numerical values: mean ± standard deviation

Overview 2:
Heat exchanger – diagram and calculations



$$\Phi = \frac{t_{22} - t_{21}}{t_{11} - t_{21}} \qquad \Phi = \frac{\text{benefit of the recovered heat}}{\text{potential of the recovered heat}}$$

or with regard to the "poultry-house ventilation" application:

$$\Phi = \frac{\text{achieved temperature increase of the ambient air } (\Delta T)}{\text{theoretically possible temperature increase of the ambient air}}$$

Symbol	Description	Unit
Φ	Temperature-transfer efficiency – indicates the thermal efficiency of heat transfer.	%
	Other terms used to mean the same in technical contexts:	
	heat-recovery efficiency, thermal-transfer efficiency	
t_{11}	Temperature of return air	°C
t_{12}	Temperature of exhaust air	°C
t_{21}	Temperature of ambient air	°C
t_{22}	Temperature of inlet air	°C
ΔT	Temperature difference = inlet air (t22) - ambient air (t21)	K
$\dot{V}$	Inlet/return-air volume flow rate	m^3/h

Indices	First number:	1 = return air
		2 = inlet air
	Second number:	1 = before the heat exchanger
		2 = after the heat exchanger

The temperature-transfer efficiency can take values between 0 and 100 %.

For example, in the field of air conditioning for buildings*, heat-recovery systems are classified with regard to temperature-transfer efficiency into six heat-recovery classes over the range of Φ = 37 % to 75 %.

Because of the different mass flow rates (inlet and return air), the following interrelation was used in accordance with DIN EN 13053, page 29:

$$\Phi_t = \Phi_{t\,1:1} \left(\frac{q_{return}}{q_{inlet}}\right)^{0,4} \quad \textit{rearranged to:} \quad \Phi_{t\,1:1} = \frac{\Phi_t}{\left(\frac{q_{return}}{q_{inlet}}\right)^{0,4}}$$

where Φ_t = *temperature-transfer efficiency without taking account of mass flow rates [%]*
$\Phi_{t\,1:1}$ = *temperature-transfer efficiency, mass-specific [%]*
q_{inlet} = *inlet-air mass flow rate [kg/s]*
q_{return} = *return-air mass flow rate [kg/s]*

* DIN EN 13053 "Ventilation for buildings – Air handling units – Rating and performance for units, components and sections"; 11:2007

Table 1:
Operating conditions

1. Operating conditions	
Housing techniques	
– Poultry fattening	
– Prolonged fattening with early removal from housing	
– Housing on litter	
Poultry-house building (manufacturer and operator information)	
– Approved places for 41,800 birds	
– Poultry-house floor space 20 m x 90 m, constructed in 2009	
– Solid construction with thermally insulated gable roof	
– Heated with gas heaters with flue-gas extraction	
– Ambient-air supply via inlet-air valves in the poultry house's side wall, return air via gable fans (forced ventilation)	
Heat exchanger	
Erected on a metal platform on the side of the poultry house	
Ventilation system	
– **Inlet air**	
Inlet air is sucked in from the outside and through the heat exchanger by the inlet-air fan and fed into the poultry-house area. Adjustable nozzles allow the inlet air to be dosed and directed (see Fig. 2, page 2). The air is distributed inside the poultry house with the adjustable nozzle and by the airflow within the poultry house that is produced by gas heaters and circulation fans.	
– **Return air**	
The return air is extracted by a return-air fan and discharged to the outdoors via the heat exchanger. In the process, the return air from the poultry house is cleared of dust by air-filter cartridges. The filters are cleaned regularly with compressed air.	
Climate computer	
AMACS climate and production computer from Big Dutchman	
2. Measuring equipment	
The temperatures were recorded in accordance with DIN EN 308.	
Temperature sensors	
– Type T thermocouples	
– Heat exchangers: 21 units in total, distributed over the inlet- and return-air sides	
– Outside temperature/ambient-air temperature: 2 units	
Humidity sensors	
– Dol 114	
– 4 units in total, 1 unit before and after the heat exchanger on both the inlet- and return-air sides	
Measuring fans	
– LMU-820 for the inlet-air volume flow rate (diameter = 820 mm)	
– LMU-710 for the return-air volume flow rate (diameter = 710 mm)	
Data acquisition	
Recording and storage of all sensor measurements at a sampling interval of 1 minute	
3. Test execution	
– Total observation period: 10 December 2012 to 29 April 2013	
– Calibration: temperature and humidity sensors at start and end of measurement	

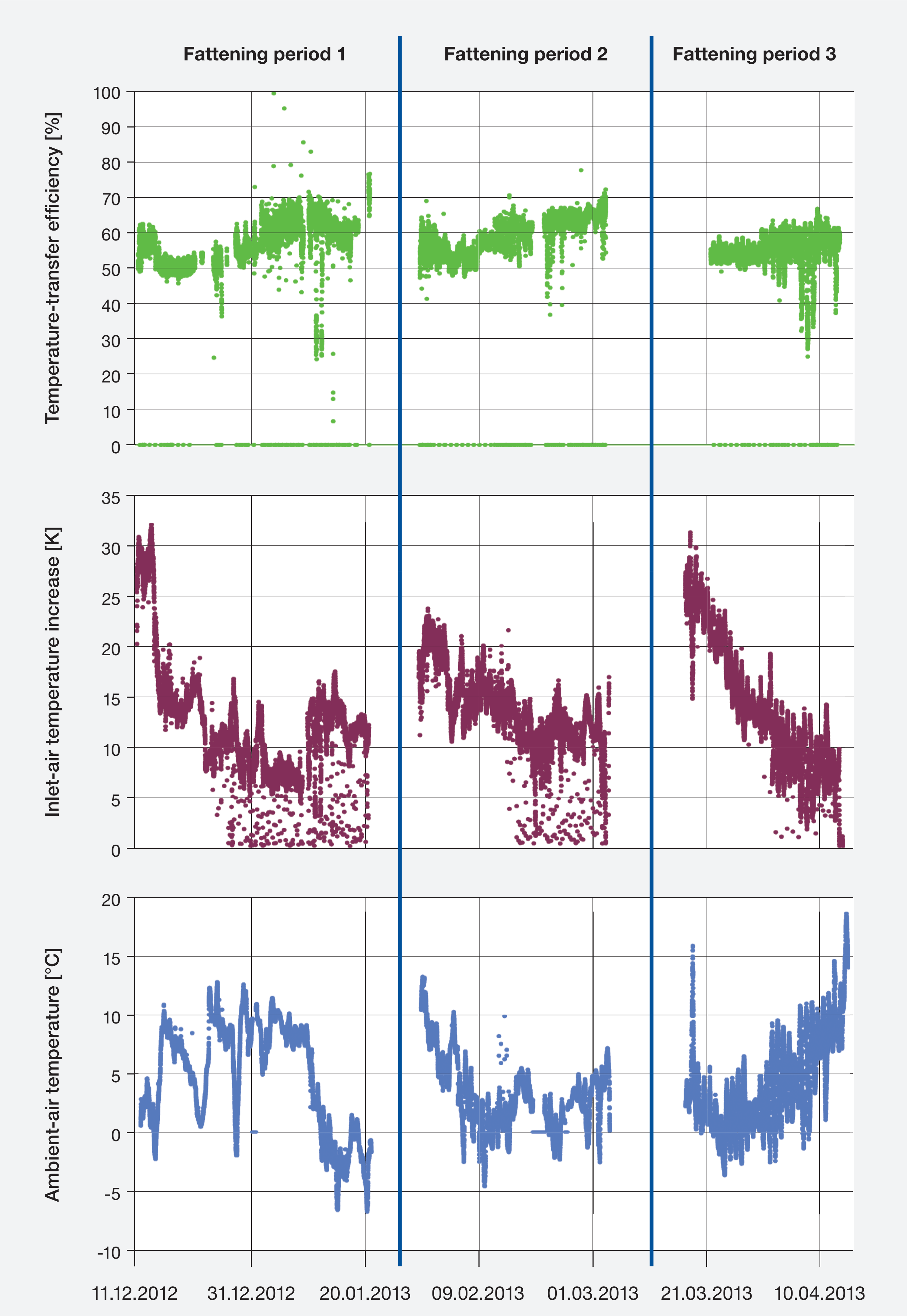
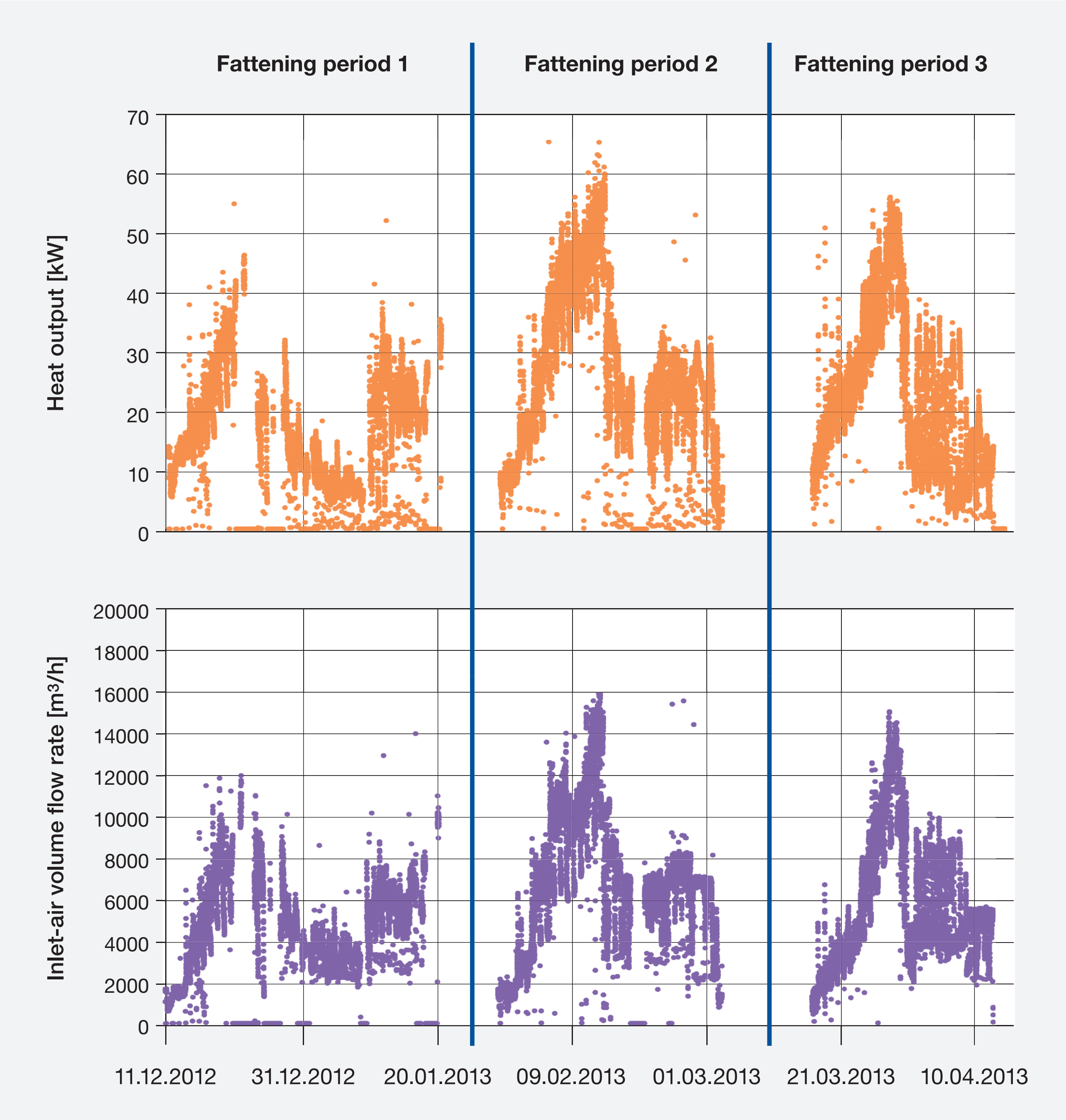


Figure 5:
Temperature-transfer efficiency, inlet-air temperature increase and ambient-air temperature over time



FATTENING DATA	**1st fattening cycle**	**2nd fattening cycle**	**3rd fattening cycle**
	Placed in poultry house on 10 Dec 2012	Placed in poultry house on 28 Jan 2013	Placed in poultry house on 16 Mar 2013
	Early harvest on 29th day of fattening (9 Jan 2013)	Early harvest on 29th day of fattening (27 Feb 2013)	Early harvest on 30th day of fattening (16 Apr 2013)
	Removed from poultry house on 42nd day of fattening (22 Jan 2013)	Removed from poultry house on 41st day of fattening (11 Mar 2013)	Early harvest on 38th day of fattening (24 Apr 2013)
			Removed from poultry house on 43rd day of fattening (29 Apr 2013)

Figure 6:
Heat output and inlet-air volume flow rate over time

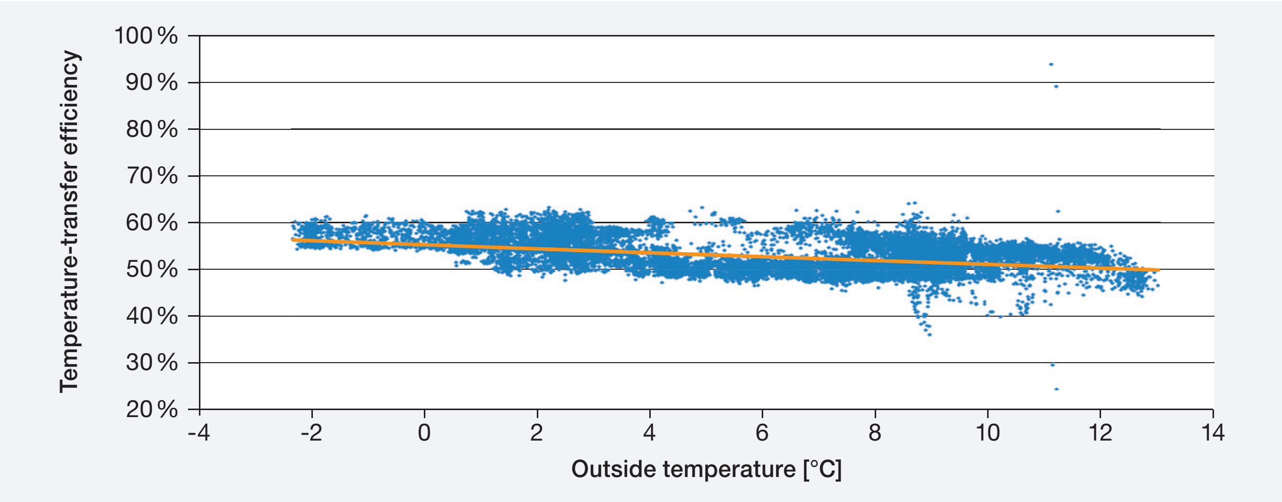


Figure 7:
Dependence of temperature-transfer efficiency on ambient-air/outside temperature

Characterisation of the heat exchanger Earny Type 40.000 according to DIN EN 308

Determination of the nominal air mass flow rate

Inlet-air fan at 100 % output = 18,639 m³/h ≙ 6.26 kg/s

Return-air fan at 100 % output = 13,058 m³/h ≙ 4.39 kg/s

Analysis of leak tightness – external leakage

External leakage is leakage between the air flowing through the heat exchanger and the environment. In accordance with DIN EN 308, the airtightness of external leakage is determined at 400 Pa of excess and negative pressure. For systems with static pressures of up to 250 Pa, DIN EN 308 allows testing of the system to be performed at 250 Pa instead of 400 Pa. The heat exchanger from Big Dutchman was tested at both pressure options (Table 2).

Analysis of leak tightness – internal leakage or internal air leakage

Internal leakage is leakage of air between primary and secondary airflows of a heat-recovery system. According to DIN EN 308, internal return-air leakage is defined as leakage from the return-air side to the inlet-air side (Table 3).

The internal leakage is measured at an excess pressure of 250 Pa on the return-air side and 0 Pa on the inlet-air side in accordance with DIN EN 308. For systems that are only designed for pressures of up to 250 Pa, DIN EN 308 allows testing of the system to be performed at 100 Pa, instead of 250 Pa, on the return-air side. The measurements were conducted at an excess pressure of 100 Pa on the return-air side.

Table 2:
Analysis of leak tightness – external leakage

	External leakage		
	Pressure [Pa]	**Leakage volume flow rate [m³/h]**	**Leakage mass flow rate [kg/s]**
Excess pressure	250	131	0.044
	400	177	0.057
Negative pressure	250	125	0.042
	400	165	0.056

Calculation for leak tightness of external leakage:

$q_{mep}/q_{mn} \cdot 100\,\% = 0.70\,\%$ at 250 Pa excess pressure

$q_{men}/q_{mn} \cdot 100\,\% = 0.67\,\%$ at 250 Pa negative pressure

Average air density over the entire measurement period = 1.21 kg · m^{-3}

q_{mn} … measured nominal air mass flow rate for inlet air [kg · s^{-1}]

q_{mep} … external-leakage mass flow rate at excess pressure [kg · s^{-1}]

q_{men} … external-leakage mass flow rate at negative pressure [kg · s^{-1}]

Table 3:
Analysis of leak tightness – internal leakage

	Internal leakage	
	Leakage volume flow rate [m³/h]	**Leakage mass flow rate [kg/s]**
Excess pressure on return-air side: 100 Pa; inlet-air side: 0 Pa	156	0.052

Calculation for leak tightness for internal air leakage:

$q_{mil}/q_{mn} \cdot 100\,\% = 0.83\,\%$ at 100 Pa pressure difference

q_{mil} … internal-leakage mass flow rate [kg · s^{-1}]

Heat balance

The change in enthalpy flow between the two flowing media was calculated as follows (for one measurement point as an example):

$$P_{inlet} = c_{p\ inlet} \cdot q_{Zu} \cdot \Delta t_{22\text{-}21}$$
$$= 1{,}006\ [kJ \cdot kg^{-1} \cdot K^{-1}] \cdot 1{,}78\ [kg \cdot s^{-1}] \cdot 14{,}4\ [K]\ [6]$$
$$= 25{,}74\ [kJ \cdot s^{-1}]$$

$$P_{return} = c_{p\ return} \cdot q_{Ab} \cdot \Delta t_{11\text{-}12}$$
$$= 1{,}007\ [kJ \cdot kg^{-1} \cdot K^{-1}] \cdot 1{,}60\ [kg \cdot s^{-1}] \cdot 15{,}4\ [K]\ [7]$$
$$= 24{,}73\ [kJ \cdot s^{-1}]$$

$$\frac{P_{inlet}}{P_{return}} = 1{,}04$$

c_p … spec. heat capacity of air $[kJ \cdot kg^{-1} \cdot K^{-1}]$
t_{21} … ambient-air temperature [K]
t_{12} … exhaust-air temperature [K]
t_{22} … inlet-air temperature [K]
t_{11} … return-air temperature [K]
q_{inlet} … inlet-air mass flow rate [kg/s]
q_{return} … return-air mass flow rate [kg/s]

Drop in pressure

The total drop in pressure is determined from the measurements in front of and behind the fan (see Tables 4 and 5).

The drop in pressure is the pressure difference along the length of a pipeline section.

Other results

Power consumption

The heat exchanger's average power consumption over the entire measurement period was 34.45 kWh per day. This figure also includes the DLG's measurement technology and the heating for the condensate tank.

Humidity

The relative humidity of the ambient air varied between 30 and 100 % over the measurement period. The inlet air fed into the poultry house had a humidity value of between 10 and 80 %, and the value for the return air from the poultry house rose from approximately 50 % to 80 % during a fattening period. It was not possible to reliably measure the humidity in the vent stack (exhaust air) until March (due to condensation effects and icing up). From April onwards, the exhaust-air humidity predominantly measured just over 90 %.

Dust

The amount of dust arising in the heat exchanger per fattening period was also investigated. For this purpose, the first and third fattening periods were analysed (Table 6).

The dust samples had an average moisture content of approximately 18 % after the respective fattening period.

Table 4:
Drop in pressure on the inlet-air side as a function of the percentage of nominal air mass flow rate

	Air mass flow rate [m³/h]	Pressure [mbar]
100 %*	18,639	> 2.40
80 %	14,911	2.25
60 %	11,183	1.81
40 %	7,455	0.83
20 %	3,728	0.36

Table 5:
Drop in pressure on the return-air side as a function of the percentage of nominal air mass flow rate

	Air mass flow rate [m³/h]	Pressure [mbar]
100 %*	13,058	> 2.40
80 %	10,446	2.29
60 %	7,835	1.60
40 %	5,223	0.90
20 %	2,612	0.31

Table 6:
Results of the dust measurements

	Period	Weight of dust [kg]
1st fattening period	11 Dec 2012 to 21 Jan 2013	4.1
3rd fattening period	17 Mar 2013 to 13 Apr 2013	7.0

Cleaning (operator information)

To allow safe and functional operation of the heat exchanger Earny Type 40.000, the appliance is to be cleaned after each fattening period. For this purpose, the filter compartment is first to be opened and the dust in the base area dispersed in water; after approx. 1 hour, the dust is to be scrubbed off, and the walls are also to be scrubbed. The filters can be rinsed with a conventional garden hose. The stopper in the filter compartment's outlet is to be removed, allowing the rinsed-off dust to escape from the area of the heat exchanger. Care must be taken to ensure that the stopper is reinserted after cleaning. The side of the heat exchanger behind the filters is also to be checked and cleaned if necessary.

Twice a year, the entire heat exchanger should be rinsed. Clean tap water is to be used to clean the heat exchanger and the components.

* For technical reasons (the measurement range was exceeded), the drop in pressure could only be reliably measured for up to approximately 80 % of the nominal air mass flow rate.

Amendment for:
[6] „$1{,}006\ [kJ \cdot kg^{-1} \cdot K^{-1}] \cdot 1{,}78\ [kg^{-1} \cdot s^{-1}] \cdot 14{,}4\ [K]$"
[7] „$1{,}007\ [kJ \cdot kg^{-1} \cdot K^{-1}] \cdot 1{,}60\ [kg^{-1} \cdot s^{-1}] \cdot 15{,}4\ [K]$"

Summary

In conclusion, the heat exchanger Earny Type 40.000 from Big Dutchman operated reliably over the measurement period.

Three full fattening periods were measured. The measurement period ran from December 2012 to April 2013. In this period, an average temperature-transfer efficiency of 57 % was achieved. The nominal volume flow rate was 18,639 m^3/h for the inlet-air flow and 13,058 m^3/h for the return-air flow. Furthermore, the heat exchanger was tested according to DIN EN 308 during the measurement period. The heat exchanger passed all of the tests.

The Big Dutchman heat exchanger Earny Type 40.000 is suitable for heat recovery in prolonged broiler production with litter for up to approx. 40,000 birds.

Test

This test report was prepared based on DIN EN 308, which is the basis for testing heat-recovery systems for HVAC (Heating, Ventilation and Air Conditioning) appliances.

The test was conducted at a broiler house in Emsland.

No survey was conducted.

Other criteria were not tested.

Test Execution

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