Validation of CFD modeling for a hybrid ventilation system in a cattle building

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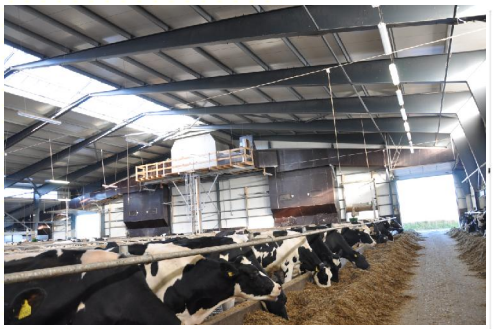
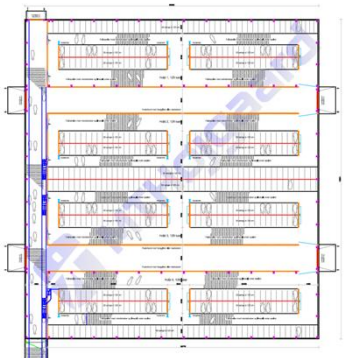
Outline

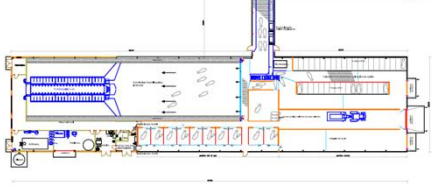
- Introduction of hybrid ventilation
- Experimental measurements
- Validation of CFD modeling
- Conclusion

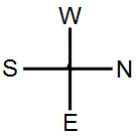
Introduction of the cattle building

Introduction of the cattle building

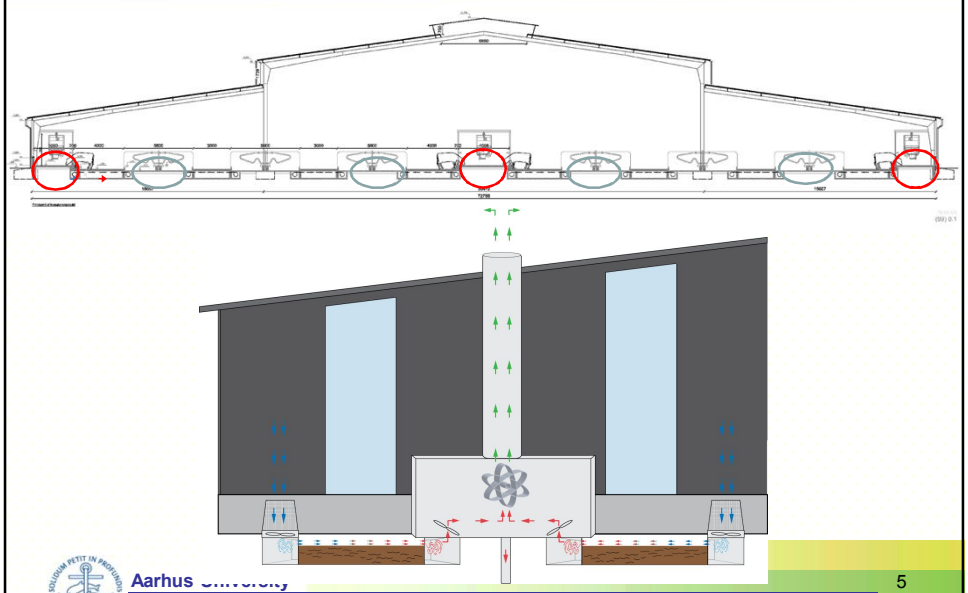








Introduction of the hybrid ventilation



Objectives of the measurements

Aims

- To documentize the performance of HV
- To identify odor compounds' distribution
- To achieve data for validation of CFD
- To achieve experience of HV design
- ……

Experimental measurements

Velocity:
Windmaster 3-Axis Ultrosinc Anemometer, Gill instruments

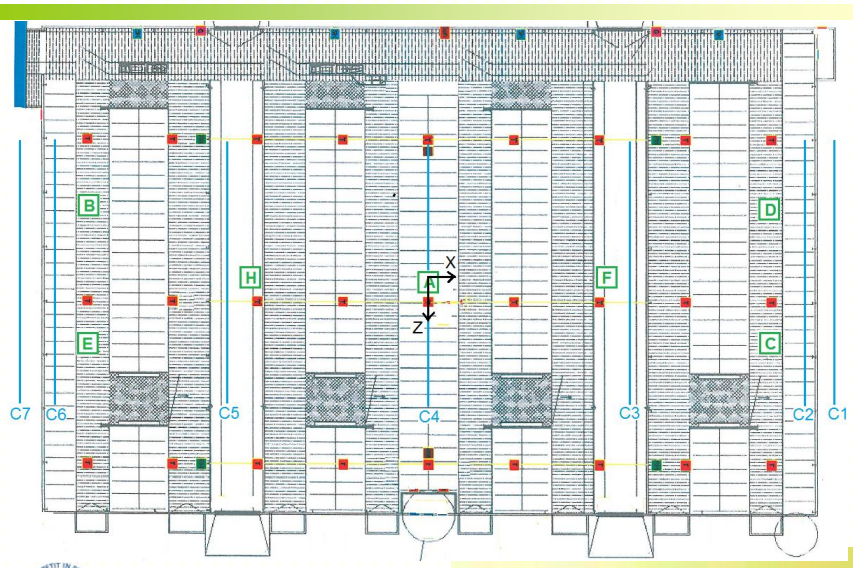
Concentration :
Photoacoustic multi-gas analyzer INNOVA 1312 and Multipoint sampler INNOVA 1309
Proton Transfer Reaction – Mass Spectrometry (PTR-MS)

Temperature:
Type T thermocouples

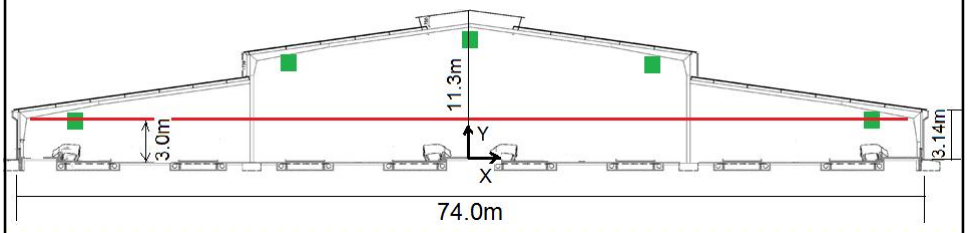
Ventilation rate in Pitvent:
Measuring fans

Experimental measurements

Experimental measurments



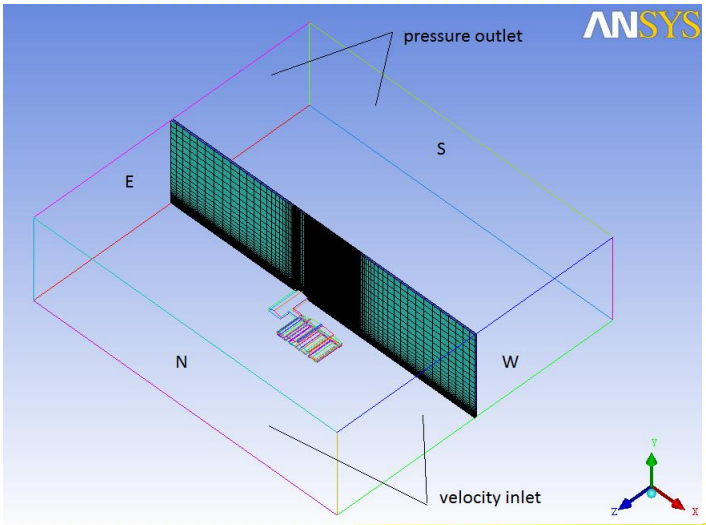
Experimental measurments



Locations of ultrasonic			
ultrasonic	x	y	z
A	0	9,9	0
B	-33,7	3,07	-6,72
C	33,7	3,08	6,73
D	33,8	3,08	-6,68
E	-33,7	3,07	6,71
F	15,34	7,5	0
H	-15,34	7,5	0

	T1	T2	T3	T4	T5	T6	T7	T8	T9
x	-32,8	-24,6	-16,4	-8,2	0	8,2	16,4	24,6	32,8
y	3	3	3	3	3	3	3	3	3
z	-12,5	-12,5	-12,5	-12,5	-12,5	-12,5	-12,5	-12,5	-12,5
	T10	T11	T12	T13	T14	T15	T16	T17	T18
x	-32,8	-24,6	-16,4	-8,2	0	8,2	16,4	24,6	32,8
y	3	3	3	3	3	3	3	3	3
z	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
	T19	T20	T21	T22	T23	T24	T25	T26	T27
x	-32,8	-24,6	-16,4	-8,2	0	8,2	16,4	24,6	32,8
y	3	3	3	3	3	3	3	3	3
z	17,5	17,5	17,5	17,5	17,5	17,5	17,5	17,5	17,5

CFD modeling --- geometry



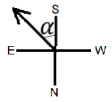
CFD modeling

Geometry and mesh	Cartesian coordinate; Structured mesh; Expansion ratio 1.2~1.3;
Numerical methods	Segregated solver, SIMPLE method Second order upwind scheme; Finite control volume;
Turbulence models	Realizable k-e models plus standard wall function
convergence criteria	Momentum equations, 1.0E-05 Continuity equation, 1.0E-04 Turbulence equations, 5.0E-05 Energy and species equations, 1.0E-06

CFD modeling -- windows opening degree

windows opening (degree)	Case 0719	Case 0807	Case 0808	Case 0809	Case 0811
east bottom	22.3	22.6	22.3	22.3	22.2
east top	20.1	20.2	19.8	19.8	20.7
east roof	24.3	24.4	24.1	24.1	24.4
east ridge	23.0	23.0	22.5	22.5	23.0
west bottom	18.0	19.4	19.9	17.4	18.5
west top	19.3	19.3	19.9	18.3	18.8
west roof	21.2	21.2	21.7	20.1	20.7
west ridge	8.0	25.0	7.7	7.7	20.0

Boundary conditions



		Case 0719	Case 0807	Case 0808	Case 0809	Case 0811
Wind conditions	U_h	2.02	3.25	3.86	2.41	2.92
	Wind angle	55.9	78.8	83.8	78.3	86.9
	Wind Tem	12.8 ℃	14.25	14.1	13.1	14.0
	CO2 (ppm)	436	430	429	428	427
Pit ventilation (m^3/h)		43223	43588	43266	41250	41422
Roof Temperature		18.0 ℃	17.8	17.4	17.2	17.8
North wall		17.6 ℃	17.3	17.0	16.8	17.4
South , west, east, wall		coupled	coupled	coupled	coupled	coupled
Window walll		coupled	coupled	coupled	coupled	coupled
Other walls		0 w/m^2	0 w/m^2	0 w/m^2	0 w/m^2	0 w/m^2

Wind profile at inlet

$$U = \frac{u_*}{k} ln\left(\frac{z + z_0}{z_0}\right) \qquad u_* = \frac{kU_h}{ln\left(\frac{h + z_0}{z_0}\right)}$$

$$k_z = \frac{{u_*}^2}{\sqrt{C_\mu}} \qquad \varepsilon_z = \frac{{u_*}^3}{k(z + z_0)}$$

U	Streamwise velocity, m/s	k_z	Kinetic energy, m^2/s^2
u_*	Friction velocity, m/s	ε_z	Turbulence energy dissipation rate, m^2/s^3
U_h	Measured velocity at height h, m/s	k	Von karman's constant,~0.4-0.42
h	Height of measured velocity, m	C_μ	0.09
z	Height above the ground, m		
z_0	Surface roughness, ~0.01m		

Richards P.J., 1993. Appropriate boundary condition for computational wind engineering models using the $k - \varepsilon$ turbulence model.

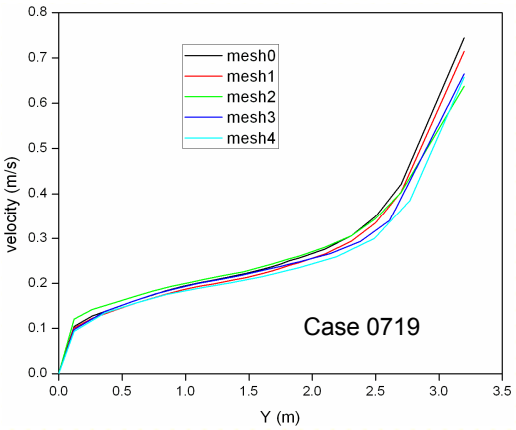
Animal occupied zone and slatted floor

$$\Delta p = 0.5 \cdot R_1 \cdot \rho \cdot v^2 + \mu \cdot R_2 \cdot v$$

Δp	is pressure drop through the porous media, Pa;
R_1	internal resistance coefficient;
R_2	viscous resistance coefficient;
ρ	air density, kg/m^3 ($1.2\ kg/m^3$ at 20℃);
v	air velocity, through the porous media, m/s;
μ	air viscosity, kg/m.s ($1.8 \cdot 10^{-5}$ kg/m.s at 20 ℃)

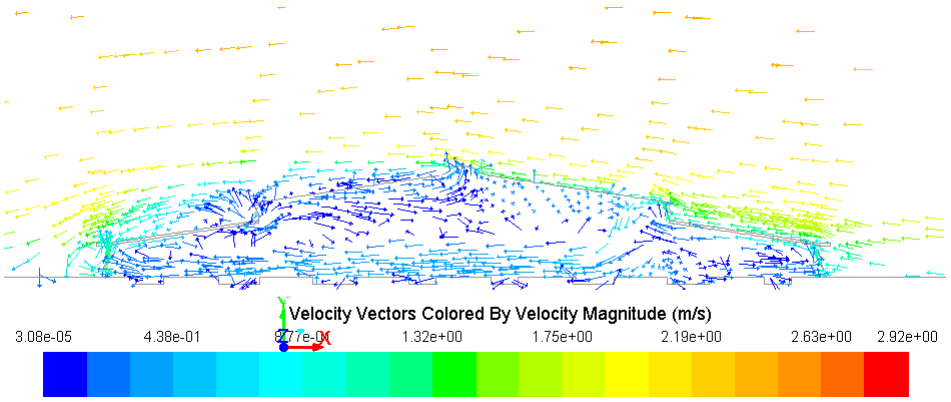
	X direcition		Y direction		Z direction	
	R_1	R_2	R_1	R_2	R_1	R_2
Animal Occupied Zone	0.06	7.71	0.06	7.71	0.06	7.71
Slatted floor with cows	-	-	40	10000	40	10000

CFD results—mesh independent study



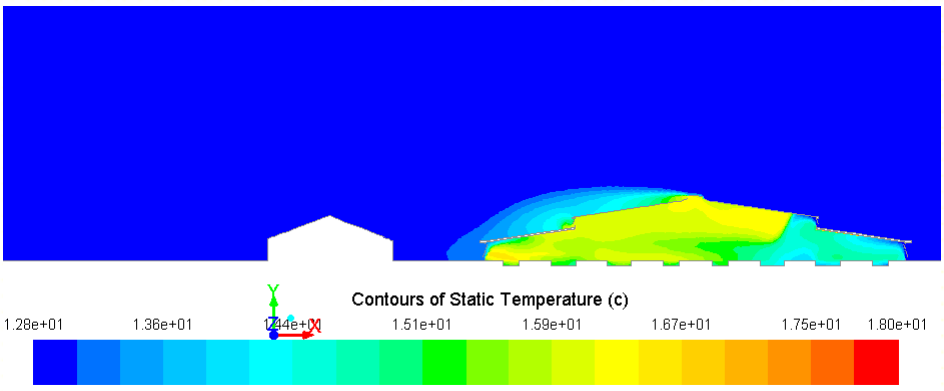
Mesh file	Mesh number
Mesh0	812 million
Mesh1	753 million
Mesh2	659 million
Mesh3	519 million
Mesh4	296 million

CFD results—case 0719



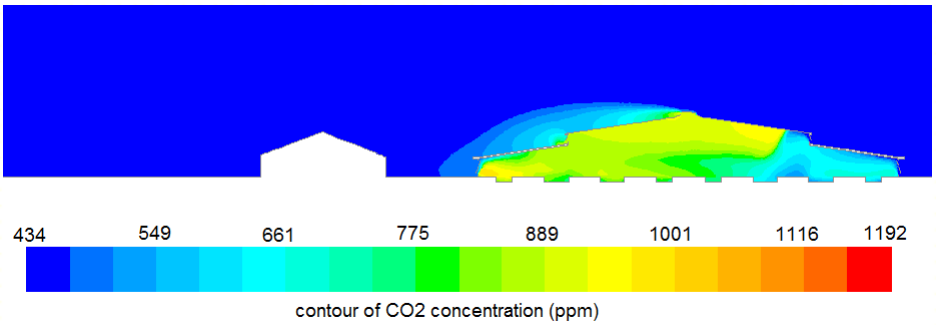
Vector distribution, z=-12.0m

CFD results—case 0719



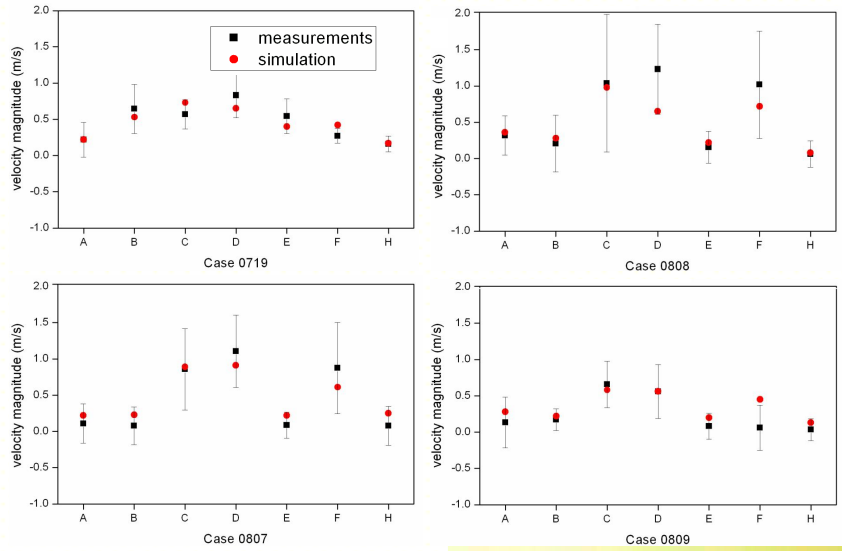
Temperature distribution, z=-12.0m

CFD results—case 0719

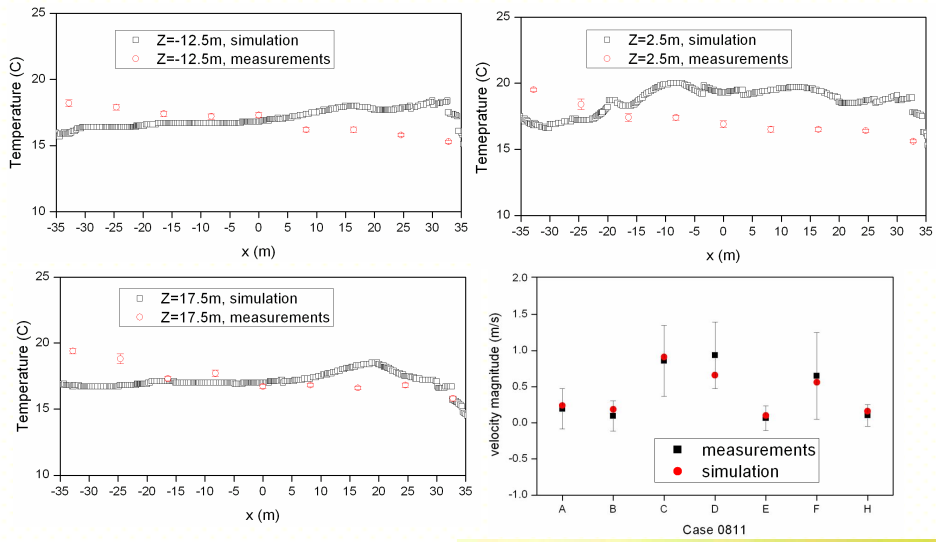


CO2 concentration distribution, z=-12.0m

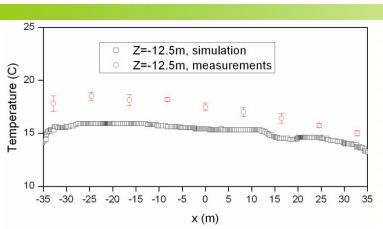
CFD modeling—velocity comparison

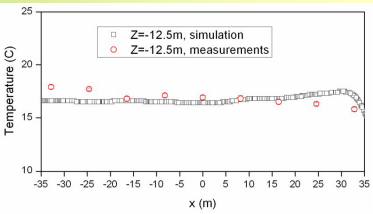


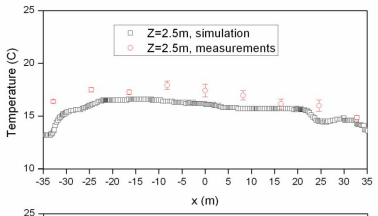
CFD modeling

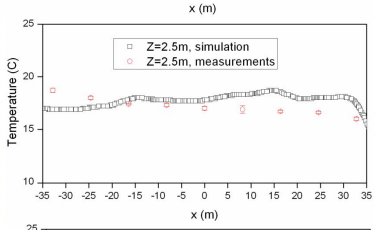


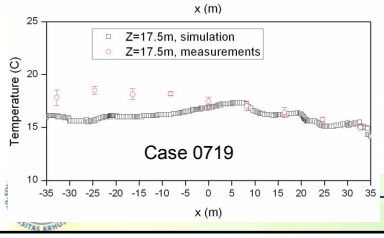
CFD modeling

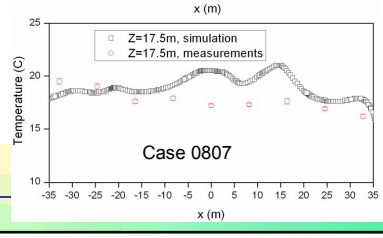












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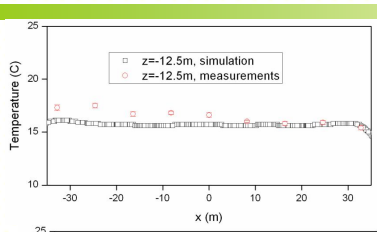
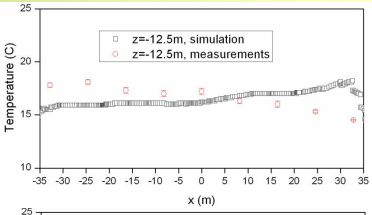
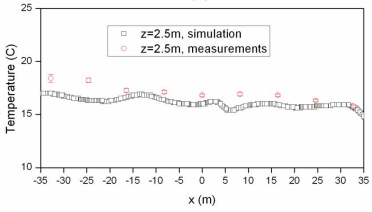
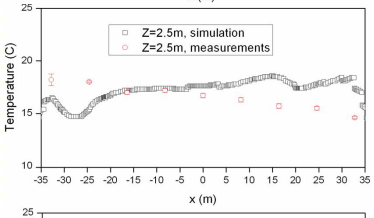
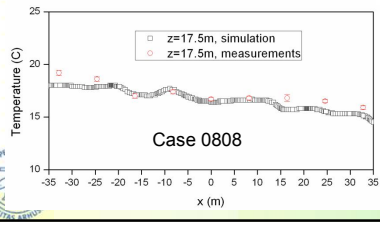
CFD modeling—Temperature profiles

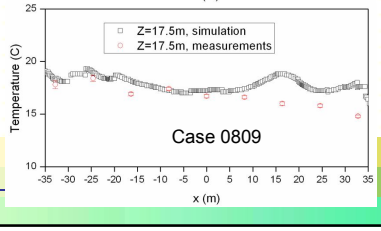












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Results

Comparison of CO2 concentration (ppm) between measurements (M) and simulations (S)

	Case 0719		Case 0807		Case 0808		Case 0809		Case 0811	
	M	S	M	S	M	S	M	S	M	S
C3	711	955	537	534	543	524	657	522	551	673
C4	1020	904	702	586	673	702	924	903	830	707
C5	1052	931	853	793	816	820	971	960	878	919
C7	478	476	781	632	589	501	491	495	572	634
CFOR	784	805	830	794	723	730	783	791	837	1106

Conclusion

- Velocity prediciton by CFD is generally in agreement with the measurements
- The simulation of temperature distribution agrees well with measurements in case 0808, but there are discrepancy between measured and simulated results in some cases.
- CO2 concentration of simulations is in good agreement with measurments. The definition of the CO2 souce in animal occupied zone is appropriate.

Thank you!

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