Technical Manual on Respiration Chamber Designs

February 2014

Edited by Cesar Pinares and Garry Waghorn

Acknowledgements

This manual has been commissioned by the New Zealand Government to support the goals and objectives of the Global Research Alliance on Agricultural Greenhouse Gases, but its contents rely heavily on the contributions from individual scientists in Alliance member countries. The participation of these scientists and their institutions is gratefully acknowledged and warm thanks are extended for their contribution to this document.

Publisher details

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Pastoral House, 25 The Terrace
PO Box 2526, Wellington 6140, New Zealand
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Fax: +64 4 894 0742
Web: www.maf.govt.nz

Copies can be downloaded in a printable pdf format from http://www.globalresearchalliance.org

ISBN 978-0-478-42361-7 (print)
ISBN 978-0-478-42362-4 (online)
February 2014

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Technical Manual on Respiration Chamber Designs

Chapter 3: ILVO's Ruminant Respiration Facility, Melle, Belgium

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3.1 Summary

The large ruminant respiration facility at the Institute for Agricultural and Fisheries Research (ILVO) comprises six airtight chambers located in a separate room (15.7 m × 7.0 m) of a stanchion barn. Wind-breaking nets are installed in the air inlets. The incoming air is not heated or cooled. The six chambers are made of polypropylene (PP) panels mounted on a stainless steel frame. Chamber volume is 12.3 m^3. The chambers operate at a slight negative pressure, with a 200–1300 m^3/h air flow. The six chambers are arranged two by two, oriented side by side along the length of the room. All chambers are monitored by one system, which performs dedicated gas sample conditioning, gas analysis, data logging and animal monitoring. Gas samples from all chambers (six) and the ambient air (two) are continuously sampled at 4 L/hour and a gas switching system delivers a sample stream to the gas analyser at intervals that vary from 5–60 seconds, depending on the measured gases. A multigas analyser measures concentrations of CH_4, CO_2, N_2O, NH_3 and water. The gas analyser is self-calibrated, with gas recovery from each chamber tested routinely. This facility has been designed for rapid and efficient feeding, milking, cleaning and animal entrance and exit, so gas emissions are monitored for more than 95% of the time under normal operational conditions. Chambers are designed for large ruminants, but can also be used for monitoring small ruminants or mono-gastric animals. Animal welfare and comfort were taken into account when designing the chambers.

3.2 Location of the facility

The physical address of the facility is:

Institute for Agricultural and Fisheries Research (ILVO)
Animal Sciences Unit
Scheldeweg 68, 9090 Melle
Belgium

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Institute for Agricultural and Fisheries Research (ILVO)
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The cow respiration chambers are located in a separate room of a stanchion barn of the Institute for Agricultural and Fisheries Research (ILVO) Animal Sciences Unit site located in Melle, Belgium. ILVO employs about 560 personnel, whereas the Animal Sciences Unit site in Melle employs about 90 persons. The experimental farm houses approximately 90 dairy cows with young stock, 75 suckling cows with young stock, 140 sows with piglets and fattening pigs (1000 in total) and 4500 broilers and 1500 laying hens. The research complex (50°59'02"N, 30°46'49"E) is located close to Melle (3 km; 11 000 inhabitants) and Ghent (10 km, 245 000 inhabitants). The stanchion barn, housing the chambers, is surrounded by pasture and other barns. There are no major industrial sites within 5 km of the facility.

The stanchion barn housing the chambers was built in 1971. The respiration room was modified in 2011. It is a brick building with a concrete frame; only the roof and part of the walls are insulated. No cooling or heating system is available. Wind-breaking nets are installed in the air inlets.

The facility houses six chambers for large ruminants in one room (Plates 1 and 2). A separate room houses instrumentation for sampling, instrument calibration, measurement and data handling. Feed preparation and cleaning facilities are nearby (in the same building), as are animal pens and equipment required for handling livestock. The six ruminant chambers are situated two by two, oriented side by side along the length of the room. The room is 15.7 m long, 7.0 m wide and between 3.8 and 5.1 m high. Animal access from the adjacent tie-stall is through a large sliding door. One door provides direct access between the room and the outside. The room has two window openings for an air inlet (Plate 3). The system layout is presented in Plate 4.

3.3 Description of the chambers structure

The respiration chambers were designed not only to enable accurate measurement of methane emissions but also of carbon dioxide, nitrous oxide and ammonia, and to provide a comfortable and safe environment for the animals. The conceptual design was based on existing chambers in The Netherlands and United Kingdom, but was thoroughly revised. Each chamber can house one large ruminant (dairy or beef cattle), but can also be adapted to house smaller ruminants and monogastric animals. Each chamber provides sufficient room for the animal while allowing rapid air exchange (1–4 minutes depending on the ventilation speed).

The volume of each chamber is 12.3 m_3, with outside dimensions of 4.0 m length, 1.55 m width and 2.8 m height, and a total weight of 1 tonne (Plate 2).

The chambers are constructed with 50 mm thick polypropylene (PP) copolymer panels (Paneltim, Belgium) mounted on an internal frame made of 80 x 80 mm stainless steel tubing (Plate 5). The panels are welded together to make the construction airtight. The construction company was Protherm (Schijndel, The Netherlands). Each chamber has three doors: an entrance door in the back, a lateral door for milking the dairy cows and a front door for feed supply, which is also the animal's emergency exit. To reduce the feeling of captivity and improve visual contact between cows, natural lighting in the chambers was maximized by using windows of 6 mm polyethylene terephtalate glycol (PETG) in each door and in the side panels.

Additional fluorescent tubes outside the chambers increase the lighting to 50 LUX inside the chambers (for animal welfare). The three other openings in the chamber are the manure tray situated under the back door, the air inlet (67 × 97 cm) in the front door and the air outlet (diameter 35 cm) in the rear part of the roof. Nine beams are welded under the floor

Plate 1: Drawing of ILVO's Ruminant Respiration Facility composed of six chambers.

Plate 2: Four of the six chambers of ILVO's Ruminant Respiration Facility.

Plate 3: Openings for air inlet, equipped with a fixed wind-breaking net with a porosity of 30% on the inside and an adjustable tarpaulin on the outside.

Plate 4: Layout of the ruminant facility. The system integrates 8 respiration chambers.

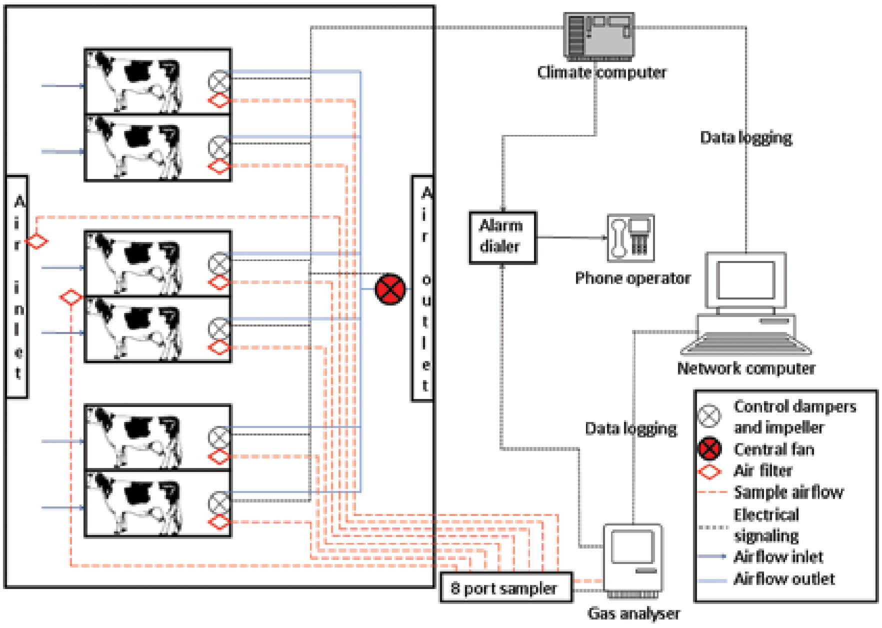


Plate 5: Inside view of a chamber made of polypropylene mounted on a stainless steel frame.

to make the chamber movable using a forklift or pallet jack. Inside the chamber, the floor is raised by 35 cm to allow for a manure tray in the rear part of the chamber (145 cm in the back). A custom made metal slatted grid is installed above the tray (Neirinck, Belgium) (Plate 5). In front, a polypropylene feed bin, 90 x 55 x 115 cm (inside dimensions) is placed with an opening for eating. A drinking bowl (F30A, La Buvette, France), with non-spill edge and water meter is attached to the side wall. To optimise the cow's comfort a Kew plus mat (Kraiburg, Germany), 183 × 130 cm, is placed on the floor. Cows are tied with a vertical chain tying system (where the tether junction could move up and down along a vertical girth/belt). The milking door is protected with bars with built-in springs for easy access (Plate 5).

3.4 Animal holding, feeding and cleaning

The group of cows is allowed to acclimate in the tie-stall for one week. The animals are accustomed to standing in a tie-stall during winter. The cows enter the chambers through the back door using a step mounted on a pallet jack and are then tied in the chambers (Plates 6 and 7). Installing the six animals in the chambers, including weighing, takes 30 minutes. Feeding, milking and cleaning the manure trays is done twice daily at fixed times. It takes two technicians 1 hour to complete.

The PETG windows allow the cows to see each other, which helps them to acclimatise quickly to the system as indicated by either eating, ruminating or lying. The chambers have a feed bin and a drinking water bowl, both easily accessible for the animal and suitable for mature lactating cows. Animals are usually kept in the chamber for two to four days.

The daily procedure enables more than 22 h of gas measurements to be made. The normal procedure is to milk the cow via the side door, to open the front door to remove any feed residues and to clean the (removable) feed bin. New feed is added, and the water supply is checked. At the rear, the faeces and urine collection tray is removed and replaced with a clean one. The removable exchangeable manure trays enable rapid cleaning of faeces and urine and minimises the daily frequency of opening the chambers. The doors are then closed and the chamber is allowed to equilibrate. Feed is usually provided twice daily, when lactating cows are milked, and leftover feed is removed once a day. We strive to minimise such refusals, by feeding just below maximal voluntary intake. Feeding is usually done at 0800 h and 1900 h.

After each experimental period, the cows leave the chamber and rooms are cleaned with a pressure washer.

3.5 Chamber airflow piping and measurement

The ventilation system is a temperature controlled mechanical central flow system (Plates 1, 4). The airflow through each chamber can range from a minimum 200 to a maximum 1300 m^3/hour (about 3 300–21 500 L/minute). The fresh air enters the room through two windows (2.3 × 1.4 m) equipped with an adjustable tarpaulin on the outside and a fixed wind-breaking net with a porosity of 30% on the inside.

The air enters each chamber via an adjustable opening (maximum 67 × 97 cm) in the lower panel of the front door, where chamber gas concentrations are monitored at 1 to 8-minute intervals, depending on the gases being measured. The air outlet is installed in the roof panel at the rear. A ventilation module with a diameter of 35 cm (ATM unit 35, Fancom, The Netherlands) is placed in the opening (Plate 8). This module connects with a 12.6 m long central ventilation duct (121 × 59 cm) made of coated plywood (Plate 1). Finally, the air is evacuated by an axial exhaust fan (FAN IF56M, Fancom, The Netherlands), with a maximum ventilation rate of 12 000 m^3/h, fixed in a chimney. In this way, one central exhaust fan creates

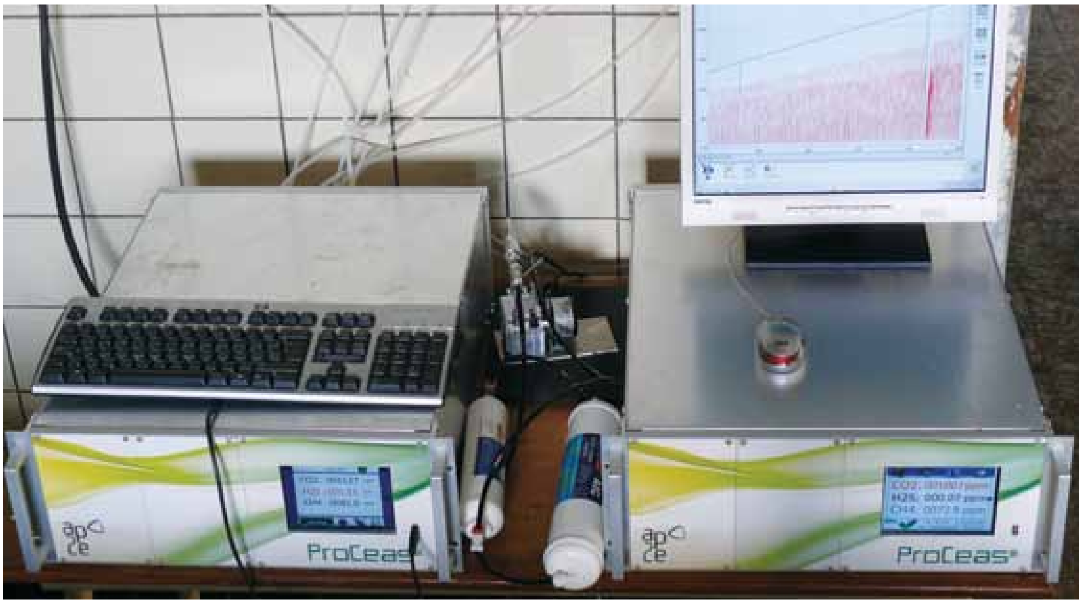
Plate 6: Cow enters the chamber through the back door using a movable step.

Plate 7: Cow tied in the chamber.

Plate 8: ATM-module with vortex damper **(grey)** and integrated impeller **(black)**. Gas sample point in ATM-module with sonic nozzle and 7 µm filter **(left)**.

Plate 9: Ventilation computer **(left)**, battery ventilation system **(right under)**, Octalarm **(right above)**.

Plate 10: ProCeas gas analyser **(right)** and 8-channel multi sampler **(left)**.



air flow through all six chambers. However, each chamber has its own ATM module with a control damper that regulates the amount of air, and an integrated calibrated full size free-running impeller that continually measures the airflow. In this module the gas concentrations are measured every 1 to 8 minutes, depending on the measured gases. The chamber with the highest demand determines the speed of the central fan. To achieve the correct volume of air in chambers with a lower demand, the vortex damper damps the air exhaust in these chambers. The unique aspect of the central flow control is that it does not simply take the section with the highest demand into account, but also continually checks the positions of all the dampers. Because of this, all the chambers have enough fresh air without any unnecessary damping. This system is managed by a F21 ventilation computer (Fancom, The Netherlands), which is temperature controlled (Plate 9). Each chamber is fitted with a sensor, close to the outlet (Fancom, The Netherlands), to monitor changes in temperature (Plate 2).

3.6 Sampling, sample conditioning and analysis

The gas concentrations of CH_4, CO_2, N_2O, NH_3 and water are measured with an infrared laser optical-feedback cavity-enhanced absorption spectrometer (IR-OF-CEAS) (ProCeas, AP2E, France) (Plate 10) in the exhaust channels in the ATM module between the impeller and the vortex damper. See Morville et al. (2005) for the principles of this technique. In each ATM-module a sample point is placed, with a stainless steel sampling probe (AP2E, France), equipped with an inline 7 µm filter and a sonic nozzle (critical flow venturi), right next to the module. The six probes are connected to an eight-channel multi sampler (AP2E, France) via 25 m of 6-mm PFA tubing. The background air concentration is measured every 1 to 8 minutes on two locations in the room, depending on the measured gases. The two probes are connected to the multi sampler as described above. The sampler is connected to the gas analyser (Plate 4). The cycling time to measure gas concentrations from the eight sampling points is completed within an 8-minute period if all gases are measured, this because of the memory effect of ammonia. If CH_4, CO_2 and N_2O gases are only measured this can be done correctly within 1 minute with three repeats per measure point. The whole measuring system functions with a continuous negative pressure of 110 mbar. This system has several advantages: no condensation, no heated lines, excellent compositional sample representation, low response time, no false positive responses, high selectivity, a measuring range from ppt to ppm in one calibration, simultaneous measurement of several gases using the same laser spectrometer and no need for coolers or driers.

The detection ranges for CH_4, CO_2, N_2O and NH_3 are 0–700 ppm, 0–5000 ppm, 0–5 ppm, and 0–70 ppm respectively, with corresponding accuracies less than 1% of the full scale. If necessary, the maximum detection limits can be lowered, to improve the accuracy of the measurements.

The gas analyser has no instrumental drift and because of the self-calibrating direct measurement, calibration is checked every 2–3 months using two standards containing a mix of gases: CH_4, 200±4 ppm; CO_2, 2000±40 ppm; N_2O, 2±0.1 ppm in N_2 and NH_3, 30±0.9 ppm in N2. The calibration gases are supplied by Air Liquide Belge (Liege, Belgium).

3.7 Gas recovery test

Chamber methane recovery tests are performed every two-three months in each chamber or if changes are made. When the system is running, pure methane (99.9%) is bled in the chamber at a rate to achieve a concentration in the air of 100 ppm. This is done through a gas mass flow meter with display (Bronkhorst High-Tech, The Netherlands), connected to a gas cylinder, for 30 min at minimum and maximum airflow rate.

3.8 Emissions calculation

Calculations of enteric emissions of gases are based on measurements of the chamber ventilation rate (Q), the net concentration of gas (C) (above the background concentration), and the percentage of gas recovery in the entire system (if implemented for this gas).

The method to measure concentrations of gases with IR-OF-CEAS gives a "wet" measurement: the air pressure is reduced to 120 mbar, but the moisture content remains volumetrically the same and the composition does not change. The dew point decreases, but that is a physical phenomenon which not affects the volumetric proportions.

In the following formulas, there are no corrections needed for temperature and atmospheric pressure, because the ventilation rate is measured with an impeller which gives a direct volumetric measurement and the gas concentrations can be displayed under standard temperature and pressure (STP; 273.15 K, 1013.25 hPa) on IR-OF-CEAS, because pressure and cell temperature are continuous monitored.

Formula "wet" emission:

$$E_{wet\ STP} = Q_{wet} \mathbf{\ x\ } [(C_{wet\ i} - C_{wet\ o}) \mathbf{\ x\ } 10^{-6}] \mathbf{\ x\ } \frac{M}{V_m}$$

$E_{wet\ STP}$ = emission concentration under wet standard temperature and pressure (g h^{-1})

Q_{wet} = ventilation rate (m^3 h^{-1})

$C_{wet\ i}$ = gas concentration air outlet (ppm)

$C_{wet\ 0}$ = gas concentration air inlet (ppm)

10^{-6} = conversion ppm (parts per million)

M = molar mass gas (g mol^{-1}; CH_4, 16.042; CO_2, 44.410; NH_3, 17.031; N_2O, 44.013)

Vm = molar volume gas at 0°C and 1 atm (0.022414 m^3 mol^{-1}), $V_m = \frac{R \mathbf{\ x\ } T_{STP}}{P_{STP}}$

R= 8.314472 10^{-2} m^3 hPa K^{-1} mol^{-1}

T_{STP}= standard temperature (273.15 K)

p_{STP}= standard atmospheric pressure (1013.25 hPa)

Formula "dry" emission is:

$$E_{dry\ STP} = E_{wet\ STP} \mathrm{\ x\ } \left(\frac{100}{100 - \%\ H_2 0}\right)$$

$E_{dry\ STP}$ = emission concentration under dry standard temperature and pressure (g h^{-1})

$E_{wet\ STP}$ = emission concentration under wet standard temperature and pressure (g h^{-1})

% H_2O = % H_2O in air sample

Formula after recovery correction (if performed):

$$E_{dry\ STP\ grr} = \frac{E_{dry\ STP}}{grr}$$

$E_{dry\ STP\ grr}$ = emission concentration under dry standard temperature and pressure with correction for gas recovery rate (g h^{-1})

$E_{dry\ STP}$ = emission concentration under dry standard temperature and pressure (g h^{-1})

grr = % percentage gas recovered during recovery test

Ventilation rate, gas concentrations and environmental parameters are continuously monitored. When these data are brought together, an emission value for any chamber within the system can be calculated every minute if the focus is on CH_4, CO_2, and/or N_2O, and every 8 minutes if NH_3 is taken into account.

Missing data, from the moment the chambers are opened until they are stabilised, are estimated by interpolation based on 20 values (20 minutes) immediately before the chambers were opened.

Once instantaneous gas emissions (g h^{-1}) are calculated for each time interval for each chamber, and the missing values have been estimated, the daily emission (for a 24-hour period) from a particular animal housed in a given chamber is calculated by time integration (area under the curve) and expressed in g d^{-1}.

3.9 Animal welfare and operators' safety

All animal experimentation must conform to good ethical considerations and are approved by the ethical commission of our institute. These chambers are designed to maximise both animal and operator safety.

The system ensures that all environmental conditions are within the thermoneutral zone for the animals, with minimal exposure to stress or risk. The system is monitored for temperature, air flow, water and gas concentrations. Alarms will activate when abnormal conditions are detected (Plate 9). If the conditions fall outside the following threshold values, the alarm system goes off and an operator is warned: temperature (higher than 26 °C), air flow (lower than 200 m^3/h), and CO_2 (higher than 5000 ppm).

Because the chambers are airtight and operate under a slight negative pressure, the most critical risk to animal safety is lack of ventilation. Consequently, power failure or malfunctioning of the ventilation system could cause CO_2 intoxication. Two safety measures have been incorporated to overcome this risk:

1. In the event of power failure, the system is designed that the damper valves of the ATM-module open completely; by this a natural chimney effect is created so the CO_2 concentrations are not harmful.

2. The respiratory chamber system is connected to ILVO’s computer network, which enables remote monitoring. Abnormal readings trigger telephone message notification to the operator or caretaker. These personnel can respond within five minutes.

Operator safety is also important. Although stainless steel frame construction is more expensive than steel, the lack of rust and easy cleaning lowers the risk of injuries and reduces labour costs. The stainless steel bars in the milking door also reduces risk of injury to the milkers and the animals. The movable step has worked very well, as has a removable manure tray (Plate 11).

Plate 11: Removable manure tray with wheels on pallet jack.

3.10 Weaknesses of the system

The main weakness of the system is the inability to provide uniform environmental conditions because it lacks conditioned air. Air-conditioning in the room can be installed if it should be necessary or an air duct with conditioned air can be attached at the air inlet of each chamber.

Polypropylene insulates quite well but double glazing would improve the insulation even more.

A typical calorimetric chamber could be more precise, but would be much more costly. No airlock exists between the room and the chamber.

A feed weighing device is absent but can be incorporated with minor changes.

Fans inside the chamber would mix the air better, with faster response time.

The chosen milking system, with tubing outside the chambers, makes it possible to work with dairy cows, but the milking door has to be opened during milking.

3.11 Description of components and equipment suppliers

Chamber structure

- Chamber frame is 80 x 80 x 3mm stainless steel tube
- Polypropylene plates; Paneltim, Lichtervelde, Belgium
- Construction structure chamber; Protherm, Schijndel, The Netherlands
- Drinking bowls F30A; (La Buvette, Charlesville-Mezieres, France), distributed by Laborim, Kortrijk, Belgium
- Custom made manure grid, Neirinck, Ruiselede, Belgium
- KEW plus laying mat; (Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany), distributed by Vanloot, Vlamertinge, Belgium

Air Circulation and pumps

- Ventilator fan, FAN IF56M, Fancom, Panningen, The Netherlands Damper with intergrated impeller, ATM unit 35, Fancom, Panningen, The Netherlands
- Managing computer, F21, Fancom, Panningen, The Netherlands
- Chimney; Fancom, Panningen, The Netherlands.
- Fancom is distributed by De Jaeger, Aalter, Belgium

Analyser, sampling and sample conditioning

- PFA tubing 6 mm for sampling; (Du Pont de Nemours, Mechelen, Belgium), distributed by CW-Technics, Lokeren, Belgium
- Gas exchange unit: 8 channel unit; (AP2E, Aix-en-Provence, France), distributed by CW-Technics, Lokeren, Belgium
- Gas analyser: ProCeas; (AP2E, Aix-en-Provence, France), distributed by CW-Technics, Lokeren, Belgium
- Micro-diaphragm pump for sample delivery to analyser: N813.3; (KNF Neuberger Inc, Freiburg, Germany), distributed by CW-Technics, Lokeren, Belgium
- Mass flow meter: EL-FLOW F-201CV-5K0-AGD-22-V; (Bronkhorst High-Tech, Ruurlo, The Netherlands) distributed by Gefran Benelux, Olen, Belgium

Data acquisition, logging and alarm system

- Standard PC, tower case (full height PCI slots to accommodate relay cards).
- Hardwire card integrated in ProCeas for communication with alarm system
- Web Link Box; Fancom, Panningen, The Netherlands
- F-Central Farm Manager; Fancom, Panningen, The Netherlands
- Backup Power Supply: 1000VA UPS
- Telephone alarm, Octalarm; (Adesys, Wateringen, The Netherlands) distributed by De Jaeger, Aalter, Belgium

References

Morville, J., Kassi, S., Chenevier, M., Romanini, D. (2005) *Applied Physics* B. 80, 1027-1038

3.12 Costs of the facility

A complete system six ruminant respiration chambers and the ancillary equipment required[#].

ITEMS	EURO	USD
LABOUR	**48,000**	**67,600**
Design of the system	3,000	4,200
Building chambers	20,000	28,000
Ventilation system	5,000	7,000
Wiring, data acquisition, software	5,000	7,000
Tests	4,000	5,600
Monitoring	7,000	9,900
Milk tubing	1,000	1,400
MATERIALS	**51,000**	**72,000**
Building materials chambers	29,000	41,000
Ventilation system	15,000	21,000
Tubing, pipes, cables, etc	3,000	4,200
Milk tubing	4,000	5,600
EQUIPMENT	**7,300**	**10,300**
Minor assets (sensors, pumps, etc.)	2,000	2,800
Gas analyser	45,000	63,000
Gas switching system	22,000	31,000
Calibration gases	1,000	1,400
Computer and data acquisition system	3,000	4,200
TOTAL COST	**170,000**	**387,200**

Excludes value added tax.