Technical Manual on Respiration Chamber Designs

February 2014

Edited by Cesar Pinares and Garry Waghorn

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Technical Manual on Respiration Chamber Designs

Chapter 1: New Zealand Ruminant Methane Measurement Centre, AgResearch, Palmerston North

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1.1 Summary

The AgResearch animal respiration facility comprises 24 airtight chambers for sheep and four for cattle. The sheep and cattle chambers are housed in adjacent but separated rooms within a dedicated facility. The rooms occupied by the sheep and cattle facilities are 32.3 m×5.8 m and 11.8 m×7.7 m, respectively. Each room has an independent ventilation (8 m^3/min) and air conditioning system, which maintains a slightly positive pressure inside the building, while providing a relatively constant temperature (15–25 °C) and relative humidity (37–45%). The sheep chambers (1.8 m^3) are constructed of aluminium (frame and floor) with clear polycarbonate walls, whereas the cattle chambers (15.8 m^3) are made from steel (structure and floor) with clear polycarbonate walls. The chambers operate at a slight negative pressure, with a set air flow of 300 and 1500 L/min for sheep and cattle, respectively. The chambers are deployed side by side along the length of the building.

For purposes of management, the sheep chambers are grouped into three independent systems, each of eight chambers, whereas the cattle chambers are all within a single system. Each system (eight sheep or four cattle) have dedicated gas sample conditioning, gas analysis, data logging and animal welfare monitoring. Within each sheep system, the chambers are grouped in two sets of 4, each sharing an air circulation system and flow adjustment manifold. Within each system, gas samples from all chambers (eight or four) and the ambient are continuously sampled at about 2.5 L/min and a gas switching system delivers a sample stream to the gas analyser over a period of about 30–60 sec, based on CH_4 concentrations stability. The gas sample delivered to the analyser is dried and concentrations of CH_4, H_2, CO_2 and O_2 are measured using a multigas analyser. The gas analyser is calibrated every morning, whereas gas recovery from each chamber is tested routinely and animal welfare is a priority.

The facility has been designed to achieve rapid and efficient feeding, cleaning and exchange of animals, so gaseous exchanges are monitored for more than 95% of the time under normal operation.

1.2 Location of the facility

The physical address of the facility is:

AgResearch Limited
Grasslands Research Centre
Tennent Drive
Palmerston North 4442, New Zealand

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Web: www.nzagrc.org.nz

The sheep and cattle respiration chambers are located at the New Zealand Ruminant Methane Measurement Centre (NZRMMC), a purpose-built facility. The facility is part of a research complex, comprising about 10 research institutions, with about 800 personnel. The research complex is located close to the Massey University campus (1 km, 9000 students) and Palmerston North city (four km, 70,000 people). The building housing the chambers is adjacent to grazed paddocks. There are no major industrial sites within 2 km of the facility.

The building housing the chambers was completed in 2011 and is of a concrete and steel construction built to New Zealand standards, which include structural design able to withstand mild earthquakes, and also insulation under floor, walls and ceiling. Electric heating and cooling facilities have been installed in order to regulate relative humidity (via a 2.4 kW condenser). Control of relative humidity in the air supplied into the building is necessary to prevent condensation within the chambers, and is usually maintained at about 40% in the inlet air stream. The building can be maintained within ± 2°C, between about 15 and 25 °C, and the usual working temperature is about 20°C. Air circulation is maintained at all times, with an exchange at 3-4 minute intervals via ceiling vents located about 3 m apart. Air pressure is not directly controlled, but positive pressure (relative to atmospheric pressure) is warranted and prevents leakage of contaminated air into the building from the surrounding areas.

The purpose-built facility houses all 24 sheep chambers in one room (Plate 1), and four cow chambers in another room. A separate room houses instrumentation for sampling, instrument calibration, measurement and data handling that is common for both the sheep and cattle systems. This room is also air-conditioned. Feed preparation and cleaning facilities are nearby (in the same building) as are animal pens, yards and equipment required for handling livestock. The 24 sheep chambers are deployed side by side along the length of the sheep room (32.3 m). Likewise the four cattle chambers are side by side along the length of the cattle room (11.8 m). Sheep access from the adjacent metabolism area is through four large sliding doors, whereas cattle access from acclimatisation area in a covered yard is through an external race.

The 24 sheep respiration chambers are subdivided into three independent system groups, each of eight chambers (Plate 2). This is for purposes of chamber ventilation control, gas sampling, gas analysis, data management and animal welfare monitoring. Each system has a dedicated sample conditioning and gas analyser. The four cattle chambers are independently managed from the sheep systems, the four chambers constituting a single system. Nevertheless, both the sheep and cattle systems operate under the same principles, being the chambers' structure and size, and ventilation rates the only differences.

The following description refers to sheep chambers in a system (Plate 2). The cattle chambers are described at the end of this chapter.

Plate 1: The sheep respiration facility comprises 24 chambers housed in a dedicated building.

Plate 2: The sheep facility comprises three independent systems. Each system integrates eight respiration chambers. The diagram shows a single system with eight chambers and the configuration of pipes for gas flow, manifold for adjusting flow, sampling lines, data acquisition, sample conditioning, etc.

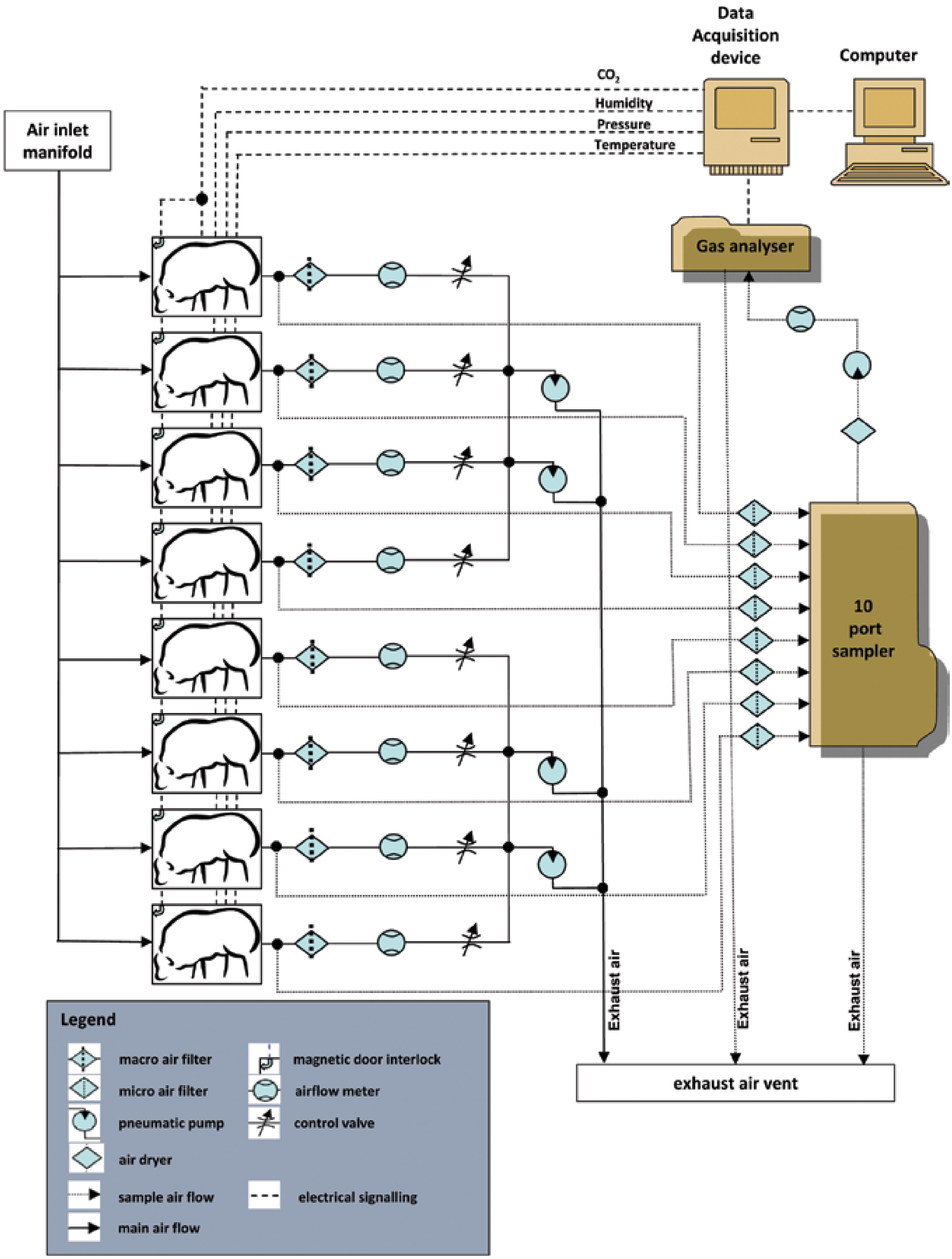


Plate 3: Structure of the sheep chamber, showing the locations of doors, air inlet/outlet, fans and sensors.

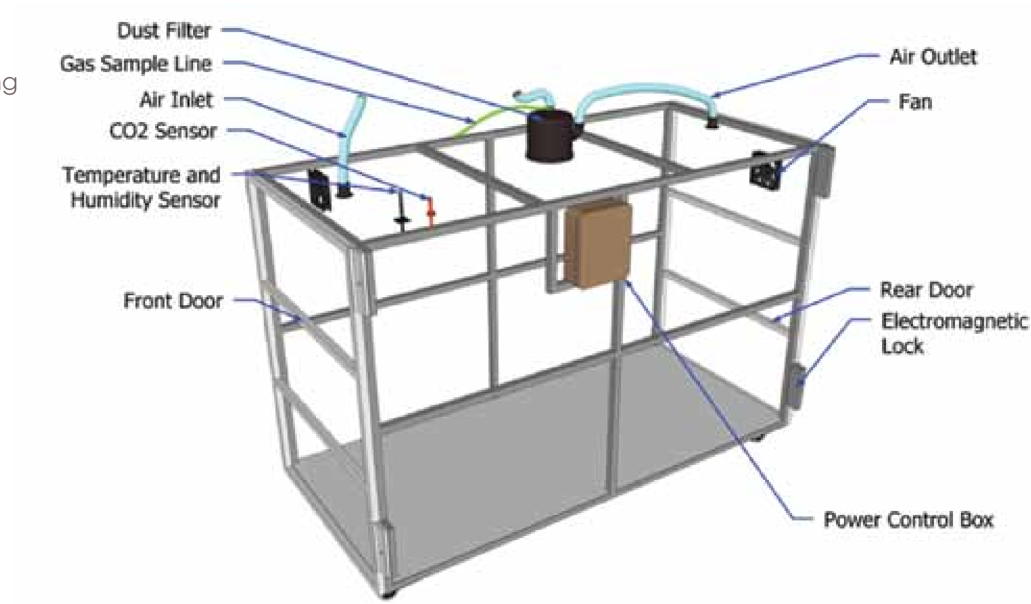


Plate 4: A modified metabolic crate used to hold the sheep in the respiration chamber.

Plate 5: A ramp is used to wheel the sheep crate into the respiration chamber.

1.3 Description of the sheep chambers structure

The respiration chambers were designed to enable accurate measurements of gaseous exchanges and provide a comfortable and safe environment for the animals. The design was derived from existing chambers in Australia and Spain and can accommodate other animal species such as goats or pigs in addition to sheep. Each chamber provides sufficient room for the animal, but enables rapid air exchange (10 air changes per h).

The volume of each chamber is 1.84 m^3, with outside dimensions (mm) of 1800 long, 850 wide, 1200 high (Plate 3). The chamber has front and rear doors covering the whole of each end, and closing onto the frame surface, with a hollow rubber strip adhered to the door where it contacts the frame, to create an air-tight seal. The frame was made of 25×25×3 mm square section aluminum tube, welded with smooth joints and the floor is 3 mm aluminum sheet welded throughout to the frame. The walls and roof are 6 mm clear UV stabilised polycarbonate sheets, each fixed to the aluminum frame using non-acetic cure silicone sealant and rubber seated TEK screws to form an air tight seal. Silicone sealant ensures no leakage around the sides and aluminum floor.

Each access door is held shut by two electromagnetic locks (Maglogs, GL650, Pivotal Solutions Ltd, Auckland, New Zealand), which are opened from the computer at feeding and cleaning times and when animals are exchanged. The rear door enables a crate with the animal in it to be wheeled into the chamber, and also is used for twice a daily exchange of faeces and urine trays. The front door is used primarily for feeding and water replacement. Both the front and rear doors also open in the event of power failure and a rise in CO_2 concentrations above a set concentration threshold (5000 ppm CO_2).

The chambers have four 100 mm diameter castor wheels, with rear ones swivelling so they can be moved easily. The front castors are lockable, whereas the two located at the back are free. In addition, the chambers have four leveling feet so the castors can be raised off the floor for added stability.

1.4 Sheep holding, feeding and cleaning

The sheep are placed in modified metabolism crates (Plate 4) that are wheeled up a ramp into the chamber (Plate 5). This is so to facilitate a rapid exchange of animals to maximise chamber operation time, and also to reduce the physical aspects of the job. In addition, a system has been developed for rapid cleaning of faeces and urine (by exchange of collection trays), again to minimise the time chambers are opened each day. Cleaning and feeding sheep

Plate 6: The mesh faecal collection tray fits on top of the stainless steel urine collection tray and both slide underneath the modified metabolism crate. Exchange of trays during cleaning is facilitated by a use of a trolley and waste bin.

in 24 chambers take 2 technicians 15 minutes. When exchanging animals is required, all the work is completed in 30 min.

The modified metabolic crates used to hold sheep have polycarbonate side panels with large (100 mm) holes to facilitate air circulation, and there are trays mounted below for faeces and urine separation and collection (Plate 6). The back of the crates are fitted with a mesh to avoid air pockets and at the same time to prevent faeces and urine falling outside the collection trays.

The clear polycarbonate sides of the crates and chambers allow sheep to see each other so that they acclimatise to the system almost immediately, indicated by either eating, ruminating or lying. The crates have provisions for holding a feed bin and a drinking water bucket (Plate 4), both easily accessible for the animal. The standard crates are suitable for sheep up to about 55 kg body weight. Large sheep should be shorn (not more than 3 cm wool cover) to ensure they have some movement, alternatively slightly bigger crates are used. Usually animals are kept in chamber for two days. Coefficient of correlation of methane emissions between day 1 and day 2 is high (r> 0.90).

The daily procedure enables >23 h of gas measurements to be made, even when sheep are exchanged. The normal procedure is to open (from the computer) the front and rear doors to remove any feed residues and clean the (removable) feed bin. New feed is added, and water supply replenished (usually 2–3 L, as required). At the rear, the faeces and urine collection trays are removed and replaced with clean trays. Doors are closed and the chamber is allowed to equilibrate. Feeding is usually twice daily, with refusals removed at each feeding. Feeding is usually at 0830 and 1630 h.

At the end of the second day of measurements, the crates holding the sheep are wheeled out of the chambers and new group of sheep in crates are wheeled in. The sheep are allowed 3 to 5 days to acclimate to the crates in the metabolism area (Plate 7), so they are easily wheeled into the chambers.

1.5 Chamber airflow piping and measurement (sheep)

Air flow through each sheep chamber is typically 300 L/min. Air is ducted through the top of each chamber, entering (inlet) the front and exiting (outlet) from the rear, with two internal fans (120 mm; 12 volt) mixing air within the chamber (Plate 3). All the chambers within a system share a common inlet source (located at the ceiling of the building) (Plate 8), which is monitored for gas concentrations at hourly intervals. A flexible 38 mm o.d. EOLO hose (Hose & Coupling Distributors, Wellington, NZ) with spiral reinforcing and a smooth interior surface is used for piping air circulation throughout the chamber systems. Each chamber is fitted with a sensor, close to the outlet (Vaisala Humicap® HMT100 (Vaisala Oyj, Helsinki, Finland), to monitor changes in relative humidity and temperature (Plate 9). In addition, a Vaisala PTB 110 barometric pressure sensor is fitted at the chamber air flow measurement device. Data on these environmental parameters enable air flows to be adjusted to dry standard temperature and pressure (STP) conditions. The sensors operate within their prescribed range, and there is no need for adjustment.

The air pumping system comprises two pumps (SCL-K03-MS, FPZ, Concorezzo (MB), Italy) enabling a continuous draw of air through the chambers. The air pump is located at the end of the air circulation system and exhaust is removed out of the building. Thus, throughout the system (chambers and ducting) a negative pressure is maintained and leakage out of the system is avoided.

Plate 7: The sheep are maintained in the metabolism area in sets of 24 animals, ready to be wheeled into the respiration chambers every second day.

Plate 8: A common air inlet (located near to the building ceiling) for the eight chambers within a system. Background air measurements are based on samples taken at this point. Temperature and relative humidity are also monitored at this point.

Plate 9: Top of the chamber showing the ducting for air to leaving the chamber via outlet **(A)**, before it is filtered **(B)** and sampled **(D)** to determine gas concentrations. The chamber is fitted with a temperature and humidity sensor **(F)** as well as a CO_2 concentration monitoring sensor **(C)**.

The air handling capacity of each pump is about 1230 L/min, but regulation of air flow is based on two sets of four chambers (Plate 10) and there is a common air flow manifold and pumping system for each set. The pumping system for each set of four chambers involves two pumps connected in parallel (Plates 2, 10).

Air flowing out of each chamber is first piped to a F198 dust filter (PVR srl, Valmadrera, Lecco, Italy) and then to a wet flow measurement unit (1 for each chamber). The outlets of the air flow measurement units are piped to a common manifold, which is used for adjustment of air flows for each chamber (Plate 10). The manifold has eight valves: four serving as inlets to receive air from each of the four chambers, whereas the other four are interconnected outlets, of which two are relief valves open to the building environment and the other two valves connect the airflow to the inlets of each the two pumps. The outlets from the pumps are exhausted outside the building (a common exhaust for two pumps) (Plates 2 and 10). Two pumps for each set of four chambers enable adjustable air flow in the range 100–400 L/min. The air flows are maintained at a constant flow and there is little variation between trials, associated with animal size (displacement).

Air flow (wet) from each chamber is measured using the principles of differential pressure within a Venturi tube, which was made by welding stainless steel tubes of 40 and 20 mm o.d. (Plate 10). The 40 mm tube has a length of 80 cm, whereas the 20 mm tube is of 40 cm. Within each tube section air pressures are measured at two different points using Vaisala PTB 100 sensors. Six mm polyethylene tubing connects the pressure sensors to the Venturi tube sections. The connectors are fitted into the stainless steel tube, but they do not extend into the Venturi, so turbulence and anomalous readings are avoided. The air flow is set to a fixed rate and, calibrated using 6–12 h serial measurements with a diaphragm gas meter (AL425, Elster American Meter Company, Essen, Germany).

1.6 Sampling, sample conditioning and analysis (sheep or cattle)

Outlet gas from each chamber is sampled continuously (2.5 L/min) immediately after the dust filter into a multiport gas switching unit (S.W. & W.S. Burrage, Ashford, Kent, UK) through 6 mm nylon tubing, with an in-line 7 µm filter.

The multiport unit switches the samples (eight chamber samples + 1 background for sheep or four chamber samples + background for cattle) at variable times (within 30–60 seconds), depending on the stability of the gas concentrations determined by the gas analyser. The gas analyser (Plate 11) determines gas concentrations at 5 sec intervals, and purpose-built software enables the gas switching system to change samples once the concentrations of CH_4 (the target gas for our purposes) from the last three readings stabilises with a variation less than 1 ppm. Sample concentrations usually stabilise within 20–45 sec, but a minimum of 30 sec and a maximum of 60 sec are allowed, whereas the background air concentration is measured hourly over a 60 sec period. The cycling time to measure gas concentrations from the 9 (sheep) or 5 (cattle) sample streams is completed within a 5-min or 3-min period, respectively.

Sample gas is delivered to the analyser by a means of a diaphragm pump (N89KNE, KNF Neuberger Inc, Freiburg, Germany) at 2.0 L/min. Before entering the analyser the sample is dried using a heated drier MDH-110-96F-4 and an unheated drier MD-110-24P-4 (both from Perma Pure, New Jersey, USA) connected in series (Plate 12). These driers have Naflon membrane elements and utilise dry air in counter flow configuration, at double the sample

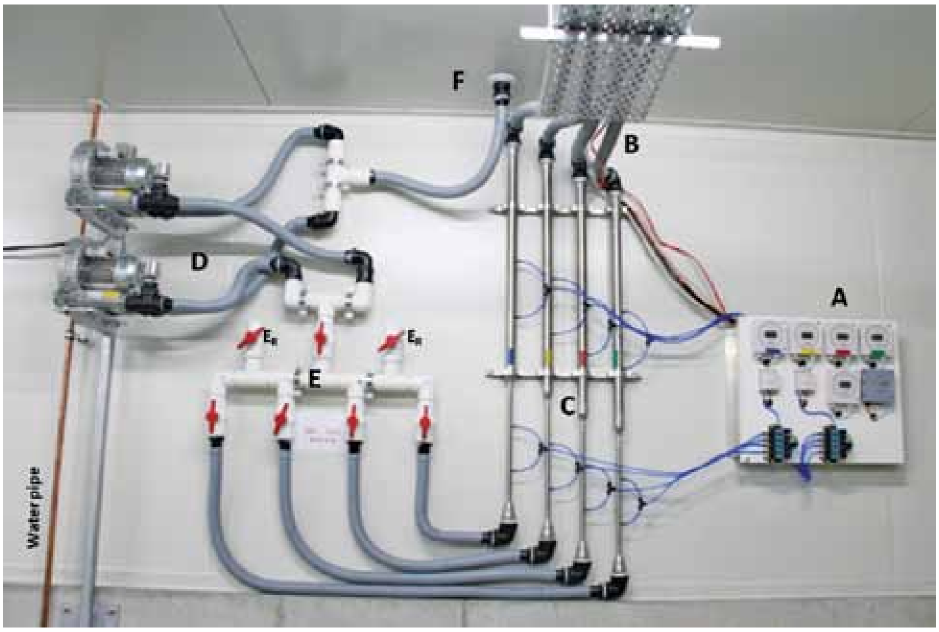


Plate 10: Chamber environment control panel **(A)**, assembly of chamber outlet pipes **(B)** with the stainless steel Venturi flow meters **(C, showing pressure outlets)**, manifold for adjustment of flows **(E, showing relief valves, ER)**, parallel assembly of pumps **(D)** and common exhaust **(F, to outside the building).** All these features are shared by four chambers within a system. Two of these sets constitute one system. The water pipe is not part of the system.

Plate 11: A dedicated gas switching unit **(middle)** and a gas analyser **(bottom)** are allocated to a system of eight chambers (sheep). A diaphragm pump (close to the gas switching unit) supplies the sample to the gas analyser, but the sample is split into two streams using a sample conditioning **(top)**, one for CH_4, CO_2 and H_2 and another for O_2.

Plate 12: Sample drying system. Sample is delivered (~2 L/min) to the analyser using a micro pump **(F)**, but is first dried using a heated drier **(D)** and then a non-heated drier **(E)**. Removal of moisture from the sample requires dry air to be circulated in counter flow (4 L/min) to sample. Dry air is generated by a self-regenerator drier **(C)**, but to avoid condensation, a refrigeration unit (B) is placed between the pump **(A)** and the dry air generator **(C)**.

flow rate. The dry air is provided by a heatless self-regenerative air drier (Nexus Analytical Pty Ltd, Australia). Room air supply to the dry air generator is via a Thomas 617CD22-194C pump (Thomas, Sheboygan, WI, USA). However, to avoid condensation inside the tubing supplying air from the pump, the air is cooled to 4°C using a thermoelectric refrigeration unit (XC3000A, Tropicool, Christchurch, New Zealand).

External to the gas analyser, the dried sample is divided into two sample streams: 1.5 L/min for CO_2, CH_4 and H_2 measurement and 0.2 L/min for the O_2 measurement, with the remaining air released. Before entering the analyser, the sample streams are filtered (0.5 µm).

Gas concentrations in dried air are measured using a Servomex 4900 gas analyser (Servomex Group Ltd., East Sussex, UK). Methane and CO_2 are measured using the infrared technology, whereas O_2 is measured using a paramagnetic cell. In addition, the gas analyser is fitted with an electrochemical H_2 detector (7HYT Citicel, City Technology Ltd., Portsmouth, Hampshire, UK). The detection ranges for CH_4, CO_2, O_2 and H_2 are 0–200 ppm, 0–2500 ppm, 0–25%, and 0 to 500 ppm respectively, with corresponding accuracies of 0.2 ppm, 25 ppm, 0.05% and 5 ppm.

The CH_4 analyser is calibrated every morning using zero gas (N_2, 99.99%) and an alpha standard containing a mix of gases: CH_4, 200±3 ppm; H_2, 100±2 ppm; CO_2, 2000±20 ppm; O_2, 21.0±0.1%, in N_2 as carrier. The calibration gases are supplied by BOC Limited (Auckland, New Zealand).

1.7 Gas recovery test (sheep and cattle)

Gas recovery tests of the respiration chamber system are independently monitored by the National Institute of Water and Atmospheric Research (NIWA, Wellington, NZ) by mass flow metering of ultra-pure CH_4 and H_2 (separately). The gas metering is set to achieve a concentration of about 100 ppm of CH_4 and 20 ppm of H_2. The metering of these gases is carried out separately, that is, no gas mix is used. It is carried out over a 1 hr period, time enough to stabilise the gas concentrations and at the same time to have an accurate ventilation rate measurement. Gas recovery tests are carried out at variable intervals depending on whether the system has suffered sizeable alterations (for example, replacement of hoses and pumps etc.), but it usually is done at about 3 month intervals. These tests revealed that the system is quite stable with mean recovery rates of 98.2 ± 0.60 and 100.5 ± 4.01 for CH_4 and H_2, respectively for the sheep chambers, while the cattle chambers have recoveries of CH_4 and H_2 of the order of 101 and 102%, respectively.

1.8 Emissions calculation

Calculation of enteric emissions of CH_4 (and other gases) is based on accurate measurements of the chamber wet ventilation rate (Wet VR), the net concentration of gas in dry sample (that is, above the background concentration), and the percentage of gas recovery in the entire system.

The wet ventilation rate (Wet VR) has to be adjusted to dry standard temperature and pressure ventilation rate (Dry STP VR). For a given point of measurement, the instantaneous emission of CH_4 is calculated using the formula:

CH_4 emission (L/min) = (Dry STP VR × ([CH_4 ppm]/1000000)) / gas recovery rate

For example, if the Dry STP VR was 290 L/min (for sheep) and the net CH_4 concentration in the sample was 50 ppm, with a gas recovery rate of 98%, the instantaneous CH_4 emission will be 0.0153 L/min. Note that the 1000000 factor converts ppm to litres.

For any chamber within a system, data for wet ventilation rate (Wet VR), gas concentrations and environmental conditions are available at 5 sec intervals over a 30−60 sec period and it is assumed that for all these variables their mean values for the last three values are representative of the 4−5 min cycle period (the case of the sheep system).

The data files are saved on daily basis (00:00 h to 23:59 h), but animal measurements usually start at about 08:30 h when animals are brought in, fed and chambers closed. Chambers are also opened to exchange excreta trays and provide feed and water at 16:30 h on day 1 and 0800 and 16.30 h on day 2. Data are collated for 24 h periods starting when chambers are first closed 08:30 h and ending after 48 hours (08:30 h). Missing data when the chambers were open are estimated by interpolation based on the 10 values (~50 minutes) immediately before the chambers were opened. With animals fed twice daily, emissions before chambers are opened for feeding are fairly stable and lower than the daily means.

The calculation of dry STP ventilation rate (Dry STP VR) requires data for relative humidity (%), temperature (^{o}C) and pressure (hPa) specific for each chamber.

Dry STP ventilation rate (L/min) =
[(Air pressure × Dry gas VR) / (Chamber T + 273.15)] × 273.15/1013.25, where pressure is in hPa, Dry gas VR is in L/min, Chamber T is the chamber temperature in ^{o}C.

Dry gas VR (L/min) *= Wet VR × [(100 – VMR)/100],* where Wet VR is the ventilation rate recorded from the flow meters (L/min), VMR is the Volume Mixing Ratio of moisture (%).

Volume mixing ratio (VMR) (%) *= 100 × PWP/air pressure,* where PWP is the partial water pressure (hPa), and the air pressure in hPa.

Partial water pressure (hPa) $= (6.1117675 + 0.4439\,T + 0.014305\,T^2 + 0.000265\,T^3 + 0.00000302\,T^4 + 0.0000000204\,T^5 + 0.00000000006388\,T^6) \times RH/100$

The partial water pressure (hPa) is obtained using the Wexler equation, where T is chamber temperature (^{o}C) and RH is the chamber relative humidity (%).

Once instantaneous emissions of CH_4 (L/min) are calculated for each interval of time for each chamber, and the missing values (when the chambers remained open) have been estimated, the daily emission (for a 24 h period) from a particular animal housed in a given chamber is calculated by time integration (area under the curve).

Daily emissions can be converted from L/day to g/day using the conversion: 1 g CH_4 = 1.3962 L CH_4.

1.9 Animal welfare and operators' safety

Animal welfare

All animal experimentation must conform to good ethical considerations. The design of these chambers is based on both animal and operator safety.

The system ensures that all environmental conditions are within the thermoneutral zone for the animals, and there is minimal exposure to stress or risk. The system is monitored for temperature, air flow, relative humidity and gas concentrations, and alarms will activate when abnormal conditions are detected (Plate 13). Should the conditions fall outside the following values, the doors open automatically and operators are called: temperature (15–24 °C), air flow (250–310 L/min for sheep; 1400–1600 L/min cattle), relative humidity (40–80%) and CO_2 (800–5000 ppm), among other indicators.

Because the chambers are air-tight and operate under a slight negative pressure, the most critical animal safety risk is the lack of ventilation throughout the system. Consequently, power failure or malfunctioning of air pumps could cause suffocation if the air flow ceased. Four safety measures have been incorporated to overcome this risk:

1. The doors of the chambers are held in place by powered solenoids and in the event of power failure they automatically open allowing fresh air to enter the chamber.
2. The vacuum pumps (two) responsible for continuous air flow are arranged in parallel to maintain air circulation even one pump fails.
3. Since four (sheep) or two (cattle) chambers are piped into a single air pumping system, any failure will result in increased CO_2 concentrations in all chambers sharing the pumping system. One sheep chamber in each set of four is fitted with a CO_2 sensor (GMP222, Vaisala Oyj, Helsinki, Finland), which is linked to the controls of power supply to all of the door solenoids and if the CO_2 concentration reaches 5000 ppm all doors of the eight chambers within a system will open. In the case of cattle chambers, each of them is fitted with a CO_2 sensor.

Plate 13: Computer (and power up system) with alarms set for abnormal environment conditions.

4. The respiratory chamber system is connected to the AgResearch computer network which enables remote monitoring. Alarms are in place for abnormal CO_2 and CH_4 concentrations, temperature, relative humidity and airflow, in which case, emails and cellular telephone messaging alert personnel. An elevated CH_4 level (> 300 ppm) may also indicate failure of the pump system and serves as a contingency in the event of a CO_2 sensor failure. Operator response is within 5 minutes when on site or 15 minutes after hours.

Operator safety

Operator safety is also important and the use of aluminum has ensured the chambers and crates are light. Although the use of aluminum for crate construction is more expensive than steel, the absence of rusting and easy cleaning compensates through lower labour costs. The ramp for wheeling sheep in and out of chambers has worked very well, as has the removable faeces and urine trays. The sieve that separated faeces from urine (Plate 6) speeds cleaning, and the trolley to hold the dirty trays removed from the chambers also reduces effort required for routine cleaning and avoids unnecessary opening of the building doors for removal of trays during cleaning. Operators' safety in the cattle chamber is warranted by allowing an area for the operator separated from the cattle area.

1.10 Weaknesses of the system (sheep and cattle)

The main weakness of the system is the inability for uniform environmental conditions to be set in all the chambers. The differences in animal size, defecation and urination events, and animal activity imply that environmental conditions inside the chambers are not only different between chambers, but conditions change within a day. The control of the temperature and relative humidity is for the building incoming air. Fitting an air conditioning system for each single chamber would be onerous and probably inefficient due to the lack of insulation in the chambers.

Occasionally delays in delivery of messages to cell phones have been experienced but this problem is outside of our control. Animal welfare was never compromised because in case of serious risk (for example, power failure) the chamber doors opened automatically.

The absence of automated feeding and feed weighing devices within the chambers limits the type of research that can be undertaken. Developments in electronics now allow the implementing of these facilities without compromising air tightness, efficiency of air mixing and response time of the system, but they still are onerous.

1.11 Description of components and equipment suppliers

Chambers structure (sheep)

- Chamber frame is 25x25x3mm aluminum tube
- Chamber floor is 3 mm aluminum sheet, with 8 mm corner sections to support
- Castors (100 mm; fixed and swivel); Wheels & Castors, Glenfield, Auckland, NZ
- Sides, doors and roof are 6mm UV Stable Polycarbonate sheet; Graley Plastics Supplies, Petone, Lower Hutt, NZ
- Fasteners; TEK screws 10-6x25 with neoprene washers; Ullrich Aluminum, Manukau City, NZ
- Silicone sealant (Bostik Industrial Grade Neutral Cure clear); Bunnings, Palmerston North, NZ
- Fans 12v DC 120mmx120mmx25mm; Globelink Limited, Palmerston North, NZ

- Switch Mode power Supplies; PSU1B 13.8 v dc 1.2amp; B&M, Palmerston North, NZ
- Electromagnetic locks (Mag lock 650-LC 1.2 amp); Pivotal Solutions Ltd, Auckland, NZ

Air circulation and pumps (sheep)

- Piping, 38 mm Eolo tubing; Hose & Coupling Distributors, Naenae, Wellington, NZ Fittings and connectors for 38 mm hoses, Hansen Products (NZ) Limited, Whangarei, NZ
- F198 dust filter (PVR srl, Valmadrera, Lecco, Italy); distributed by HIVAC Ltd, Silverdale, Auckland, NZ
- Air pumps (SCL-K03-MS, FPZ, Concorezzo, MB, Italy), distributed by HIVAC Ltd, Silverdale, Auckland, NZ
- Test gas meter to calibrate Venture flow meters, AL425, Elster American Meter Company, Essen, Germany

Sensors, analyser, sampling and sample conditioning (sheep or cattle)

- Environment sensors: Temperature and relative humidity (Vaisala Humicap® HMT100), pressure (PTB 110), and CO_2 concentration (GMP222), all from Vaisala Oyj (Helsinki, Finland), distributed by Vaisala Pty Ltd, Hawthorn, Melbourne, Australia
- Nylon tubing 6 mm for sampling; Norgren, Palmerston North, New Zealand
- Gas switching unit: 10 channel unit; S.W. & W.S. Burrage, Ashford, Kent, UK
- Unit for splitting sample into two streams: Applied Instruments Group (2007) Ltd, South Auckland, Auckland, NZ
- Gas analyser, Multigas 4900 gas analyser (Servomex Group Ltd., East Sussex, UK), distributed by Applied Instruments Group (2007) Ltd, South Auckland, NZ
- Micro-diaphragm pump for sample delivery to analyser: N89KNE (KNF Neuberger Inc, Freiburg, Germany), distributed by HIVAC Ltd, Silverdale, Auckland, NZ
- Heatless Nexus HLD dry air generator; Nexus Analytical Pty Ltd, Engadine, NSW, Australia
- Pump for fresh air supply to the cooler: Thomas 617CD22-194C, distributed by Nexus Analytical Pty Ltd, Engadine, NSW, Australia
- Heated and non-heated sample gas drier using Naflon membrane from Perma Pure (NJ, USA), distributed by Nexus Analytical Pty Ltd, Engadine, NSW, Australia
- Air cooler (XC3000A, Tropicool) to supply cool air to the dry gas generator; Tropicool, Christchurch, NZ

Data acquisition and logging (sheep or cattle)

- Standard PC, tower case (full height PCI slots to accommodate relay cards)
- Relay output card: DASP 52032 PCI-16 channel relay output card: Jenlogix Ltd, Auckland, NZ
- Data acquisition: Picolog 1216, 16 channel, 12 bit resolution Data acquisition module; distributed by Metermaster Ltd, Auckland, NZ
- Control system software, custom software written in Visual Basic 6.0, Microsoft, USA
- Backup Power Supply: 650VA UPS (Cat No. MP-5204); JayCar, Palmerston North, NZ

1.12 Costing of the sheep facility for a complete system of eight respiration chambers and the ancillary equipment required

ITEMS	NZ$	US$
LABOUR FOR		
Design of the system	2,000	1,600
Building of chambers	35,000	28,000
Piping air circulation and sample lines	2,000	1,600
Wiring, data acquisition, software development	15,000	12,000
Monitoring and commissioning	10,000	8,000
Tests	3,000	2,400
MATERIALS		
Building materials	30,000	24000
Pipes, cables, etc	4,000	3200
EQUIPMENT		
Minor assets (sensors, pumps, etc)	20,000	16,000
Gas analyser	40,000	32,000
Sample drying system	5,000	4,000
Gas switching system	6,000	4,800
Calibration gases	2,500	2,000
Computer and data acquisition system	5,000	4,000
TOTAL COST[1]		143,600

1.13 AgResearch cattle respiration chambers

The cattle respiration facility involves four chambers, housed in a room (11.8 m×7.7 m) adjacent to the sheep respiration facility. The air conditioning system for this room is similar to that for the sheep system, but independently controlled. The chambers were constructed from mild steel rectangular hollow tube sections, and covered in clear 6 mm thick UV stable polycarbonate sheet. The net volume of each chamber is 15.8 m^3 and 4.0 m long, 2.0 m wide and 2.2 m high. Due to their size and building access, it was necessary to construct the chamber in two halves. Then the two halves were bolted together inside the facility using a full bead of silicone sealant ensuring a stable airtight seal.

The main frame of the chamber uses 70 ´ 50 ´ 5 mm steel tube for its superstructure and 50 ´ 50 ´ 5 mm steel tube for the sub-frames, with animal/operator safety dividing partitions fabricated from 30 ´ 30 ´ 3 mm steel tube. The floor of the chamber is 6 mm thick mild steel plate welded to the main frame and silicone-sealed. The clear polycarbonate covering walls, roof and doors of the chamber are fixed to the metal frame using neutral-cure silicone sealant and rubber-seated TEK screws at 100 mm centres to ensure air-tightness. The chamber has one front and two rear access doors fitted with rubber seals. The front door (115 cm wide ´ 215 cm high) is located at the left side and closed by two electro-magnetic locks. In the event of either a power failure or a CO_2 build-up to predetermined levels, the door locks de-energise, and the doors spring open allowing a fresh air supply to reach the animals. This door is also used for animal feeding.

Plate 14: Design of the cattle chamber showing its structural frame and ancillary equipment. The frame is covered with clear walls and roof.

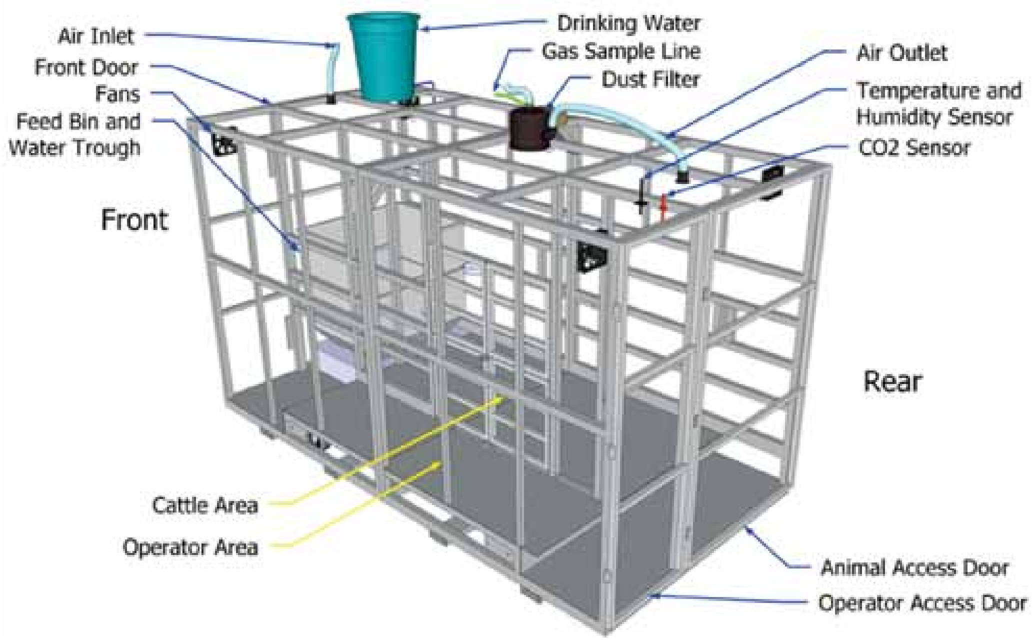
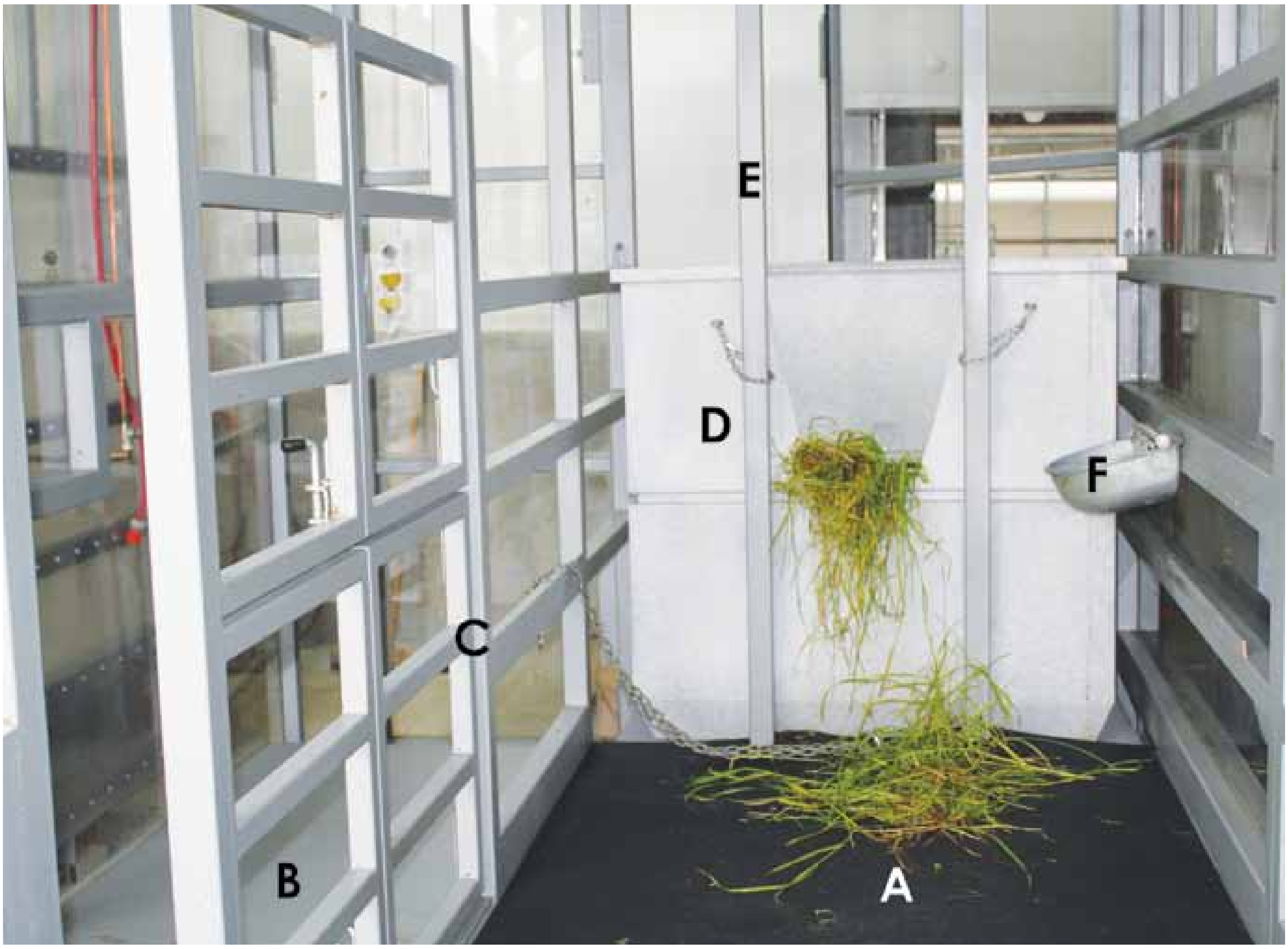


Plate 15: Internal view of the chamber showing the cattle area covered in a rubber mat **(A),** the operator area **(B)**, the protection frame **(C)**, feed bin **(D)**, the bars to avoid cattle passing throughout the front door (E) and the water trough (**F**).



The two rear doors are hinged on either side of the chamber (Plate 14). The main rear door (115 cm wide ´ 215 cm high) located at the right side is used for animal access, whereas the smaller door (90 cm wide ´ 215 cm high) located at the left side is used for operator access. These doors are secured with three large clamping wing nuts ensuring that an air-tight seal is achieved by the door against the main chamber frame.

The main floor is the whole width of the chamber and is 20cm higher than recesses in the front (80 cm deep) and rear (65 cm deep). The chamber comprises two sections (A and B; Plate 15). Section A (117 cm wide and 250 cm long) is the cattle holding area and is covered in rubber mats. Section B (90 cm wide and 250 cm long) is the operator safety area and is separated from section A by an internal metal frame with 'easy-access' openings for rumen sampling. The low floor at the front is used for placement of the feeding bin, whereas the low floor at the rear is where the excreta collection bins are placed. Drinking water is provided by a water trough located at the right internal wall of the chamber. For reasons of safety and requirements for measuring water intake, the water supply is piped from a 50 L covered bucket located on top of the chamber.

A removable head bail is built into the chamber to prevent cattle from turning around. It allows easy movement of the animal during feeding, drinking, resting and lying down. However, for well acclimatised animals, the head bail is removed and instead a neck collar is used to tie the animal down to the floor of the chamber. The front of the cattle housing area has two perpendicular metal bars to prevent the animals passing through the front, but these bars do not impede access to the feeding bin. The rear of the cattle area is designed so that a metal bar can be placed behind the animal, 70 cm above the floor, to prevent the animal stepping into the excreta collection bin. The chamber has provisions for adjusting the water trough and head bail to suit different size animals (for example, calves and adults). The whole chamber is leveled using four adjusting screws that can be retracted so the chamber is able to be maneuvered on large braked castors. The animals access and exit the chamber throughout the rear door.

The chamber is fitted with a fresh air inlet in the front section of the ceiling and an air outlet in the rear ceiling. All the piping for air circulation is through flexible polyurethane hoses (51 mm o.d.). The air inlet is piped from an air intake in the ceiling of the building. Incoming fresh air and the respiratory gases are mixed by four fans located at the top corners of the chamber. The outlet hose is connected to a 51 mm air filter (F300, P.V.R. srl, Valmadrera, Lecco, Italy) and then to a wet gas flow measurement system. The gas flow measurement system is based on the differential pressure principles, similar to that for the sheep chambers, except that the large diameter (50 mm o.d.) and small diameter (30 mm o.d.) stainless steel tubes are 100 and 50 cm in length, respectively. The gas flow system is calibrated using a quantometer (Qa100-80-016, Elster/Amco, Malnz-Kastel, Germany). The outlet from the gas flow measurement system is connected with polyurethane hoses to a manifold and then to a vacuum pump system using side-channel pumps (SV 7.190/1-01, Gebr. Becker Gmbh & Co., Wuppertal, Germany). Two pumps connected in parallel, draws air through two chambers at continuous but adjustable flow rates (1000–2000 L/min). Air (with respiratory gases) exiting the air pump is exhausted outside the building. Relative humidity and temperature sensors are installed in the chamber, as with the sheep chambers for standardisation of the gas flow. Air pressure is measured at the gas flow measurement system.

Gas sampling, sample conditioning and analyses are conducted as for the sheep system. An exception is that gas analysis cycles for the cattle system are shorter than for sheep due to the smaller number of cattle chambers (four versus eight for sheep). Similarly, all the safety measures found in the sheep system are installed in the cattle respiration facility.

The performance of the system is evaluated using the gas recovery protocol as for the sheep chambers.

The cost of a facility comprising a four-chamber system for cattle is about NZ$250,000 (US$200,000), with labour (excluding design, software development and commissioning), materials and equipment comprising 15, 55 and 30% of it, respectively.