Water Balance and Moisture Production of Grower-Finisher Rooms in Swine Production Using Dry and Wet/Dry Feeders

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ABSTRACT

Two components were associated with this research project. The first component established and measured the water balance of a grower-finisher room in an intensive swine operation (ISO) using dry and wet/dry feeders. The second component verified various moisture production (MP) prediction equations for ISO's using current MP values. Knowledge of the significant sources and sinks of water in an ISO will allow future research on water conservation to focus on key areas.

Six separate grower-finisher cycles were followed and the parameters of the water balance, including water from the drinkers, in the feed, metabolic reactions, within the pig, ventilated from the room and in the slurry, were measured for each cycle. The significant source of water was at the drinker, at 72% of the total water source, and the major sink of water was in the slurry, at 64% of the total water sink. The use of wet/dry feeders compared to dry feeders significantly reduced both the water disappearance at the drinker by 34% (p<0.05) and the volume of the slurry by 29% (p<0.05).

If the current MP is actually higher than predicted in swine barns, the minimum ventilation rate to control the humidity level of the room needs to be higher than the current design criteria. If the minimum ventilation rate increases, the current heater capacity may not be sufficient to compensate for the additional heat loss. Comparisons of MP were made using measured and predicted values to determine
the validity of the equations currently used for design purposes. CIGR (1984) yielded the best estimates for MP, but underestimated the average MP by 8% for all cycles. CIGR (2002) and Bond et al. (1959) also underestimated the average MP by 13 and 31%, respectively. Diurnal MP patterns were not predicted by the MP equations.

To conserve water and reduce the volume of manure, wet/dry feeders should be used in place of dry feeders and nipple drinkers, and future research should be done with both drinkers and manure. Additionally, the current MP equations used in this study need to be updated to reflect current MP by grower-finisher swine.
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To Mom and Dad

For supporting me in every decision I make
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$\Delta W_{\text{pig}}$: difference in water content of pig at beginning and end of cycle (kg·pig$^{-1}$·day$^{-1}$)

$A_{100}$: relative activity (average = 100)

ADFI: average daily feed intake (kg·pig$^{-1}$·day$^{-1}$)

ADFW: average daily feed water (kg·pig$^{-1}$·day$^{-1}$)

ADG: average daily gain (kg/day)

ash: ash in the feed (%)

b/a: amplitude (43)

b: experimental coefficient

BW: body weight (kg)

C: carbohydrates in the feed (%)

c: pressure coefficient

$C_{\text{catabolic}}$: carbohydrates available for metabolic reactions (kg·pig$^{-1}$·day$^{-1}$)

CF: crude fat in the feed (%)

$C_{\text{faeces}}$: carbohydrates lost in the faeces (kg·pig$^{-1}$·day$^{-1}$)

$C_{\text{in}}$: carbohydrates into the pig via feed (kg·pig$^{-1}$·day$^{-1}$)

$C_{\text{metabolic}}$: water created from metabolic reactions of carbohydrates (kg·pig$^{-1}$·day$^{-1}$)

CP: crude protein in the feed (%)

$C_{\text{retained}}$: carbohydrates retained by the pig (kg·pig$^{-1}$·day$^{-1}$)

F: temperature correction factor

F1: finisher phase, experiment one
F2: finisher phase, experiment two

FC: feed conversion (kg_{feed}/kg_{gain})

F_{catabolic}: fat available for metabolic reactions (kg·pig^{-1}·day^{-1})

FD: feed disappearance (kg·pig^{-1}·day^{-1})

F_{faeces}: fat lost in the faeces (kg·pig^{-1}·day^{-1})

F_{in}: fat into the pig via feed (kg·pig^{-1}·day^{-1})

F_{metabolic}: water created from metabolic reactions of fat (kg·pig^{-1}·day^{-1})

G1: grower phase, experiment one

G2: grower phase, experiment two

H: static pressure head across the fan (Pa)

h_{min}: time of day with minimum activity (hours after midnight 1.3)

ISO: intensive swine operation

k_s: correction factor for floor type (0.91)

K_{Y}: coefficient of energy at weight gain

m: mass of pig (kg)

Met W: metabolic water (kg·pig^{-1}·day^{-1})

MP: moisture production (g·15min^{-1}·kg^{-1})

MW: manure water (kg·pig^{-1}·day^{-1})

n: daily feed energy intake in relation to Φ_m

N: fan speed (rpm)

n_{hpu}: number of heat producing units

P_{catabolic}: protein available for metabolic reactions (kg·pig^{-1}·day^{-1})

P_{faeces}: protein lost in the faeces (kg·pig^{-1}·day^{-1})
$P_{in}$: protein into the pig via feed (kg·pig$^{-1}$·day$^{-1}$)

$P_{metabolic}$: water created from metabolic reactions of protein (kg·pig$^{-1}$·day$^{-1}$)

PR: protein retained by the pig (%)

$P_{retained}$: protein retained in the pig (kg·pig$^{-1}$·day$^{-1}$)

PSCI: Prairie Swine Centre Inc.

PW: pig water content (kg·pig$^{-1}$·day$^{-1}$)

$r$: specific heat of water, (2430 J/g$\text{H}_2\text{O}$)

RH: relative humidity (%)

t$: inside ambient temperature (°C)

V: airflow at some static pressure (L/s)

VR: ventilation rate (m$^3$/s)

WD: water disappearance (kg·pig$^{-1}$·day$^{-1}$)

$W_{drinker}$: water disappearance from drinker (kg·pig$^{-1}$·day$^{-1}$)

$W_e$: humidity ratio of exhaust air (kg$\text{H}_2\text{O}$/kg$\text{dry air}$)

$W_{feed}$: feed water content (kg·pig$^{-1}$·day$^{-1}$)

$W_{met}$: water produced through metabolism (kg·pig$^{-1}$·day$^{-1}$)

$W_o$: humidity ratio of outside air (kg$\text{H}_2\text{O}$/kg$\text{dry air}$)

$W_{slurry}$: water in slurry (kg·pig$^{-1}$·day$^{-1}$)

$W_{vent in}$: water in through ventilation (kg·pig$^{-1}$·day$^{-1}$)

$W_{vent out}$: water out through ventilation (kg·pig$^{-1}$·day$^{-1}$)

$W_{vent}$: difference of water in and out through ventilation (kg·pig$^{-1}$·day$^{-1}$)

$v$: specific volume of dry air (m$^3$/kg$\text{dry air}$)

$\Phi_d$: daily feed energy intake (W)
\[ \Phi_I: \text{ latent heat production (J/s)} \]
\[ \Phi_{I\text{-pig}}: \text{ latent heat production per pig (W/pig)} \]
\[ \Phi_m: \text{ heat dissipation due to maintenance (W)} \]
\[ \Phi_{s\text{ cor}}: \text{ sensible heat production corrected for floor type (J/s)} \]
\[ \Phi_s: \text{ sensible heat production (J/s)} \]
\[ \Phi_{\text{tot}}: \text{ animal total heat dissipation in the barn (W)} \]
\[ \Phi_{\text{tot-hpu}}: \text{ animal total heat dissipation per hpu (1000 W in total heat at 20°C, W)} \]
1.0 GENERAL INTRODUCTION

Intensive swine operations (ISO's) are becoming larger and increasingly concentrated to efficiently meet the demands for pork consumption worldwide. This growth and concentration of ISO’s places a great load on the water sources. In addition, any water wasted by the ISO increases both the water demands and the volume of slurry to be stored, handled and transported. For reasons of water conservation and financial concerns, it is desirable to identify the sources and sinks of water in an ISO. The significant sources and sinks of water may then be pinpointed so future research may efficiently focus on reduction and recycling of water in ISO’s.

Concerns arising from the storage, transport and spreading of effluent resulting from wasted water in ISO’s are justified. For a single 5000 farrow to finish pig barn in Saskatchewan, Canada it would cost about $8,600 per year just to spread the spilled water, based on manure spreading costs (Lemay and Chénard 1998). In some countries, such as the UK, planning permission to build a pig unit is unable to be obtained unless the owner is able to demonstrate that sufficient land area is available
for suitable manure disposal without adverse effects on the environment (Brooks 1994). In addition, the demand on the water source is a primary concern, as potable water is becoming a limited resource worldwide (Brooks 1994).

Another key issue in ISO’s is knowledge of the moisture production (MP) within the rooms. At the house level MP within the room is from two primary components: evaporation from the animals and evaporation from building surfaces and animal wastes. Knowledge of the MP at the house level is necessary for proper design of room ventilation systems. In cold conditions the room needs to be ventilated to control for MP to prevent pathogenic organism survival and condensation, which promotes building and equipment deterioration (ASAE 2002a). The relative humidity in the room should not exceed 80% (ASAE 2002a; ASHRAE 2001; Massabie et al. 1997) to minimise condensation and adverse health effects, and the RH should not be lower than 40%, which may contribute to excessive dustiness within the room (ASAE 2002a). When ventilating for moisture control, supplemental heat is added to the air to compensate for the heat loss and maintain the room set point temperature. Over-ventilation increases the costs for supplemental heating, and under-ventilation may create moisture problems within the room. If the MP is underestimated when designing the ventilation system and the minimum ventilation rate is later adjusted, the heater capacity may be insufficient to maintain the room setpoint temperature. As a result the room temperature may reach levels below that of the thermoneutral zone, which leads to poor pig production and possibly pig deaths if critical temperatures are reached (Bruce and Clark 1979).
This project focuses on determining the significant sources and sinks of water in a grower-finisher room, as well as comparing the differences between dry and wet/dry feeders to determine where future research efforts on water conservation should focus. In addition, this project tests the viability of various MP equations to determine if the equations are able to predict the actual MP in modern swine barns.
2.0 LITERATURE REVIEW

2.1 Introduction

Water is an integral part of any swine operation, as both a nutrient for the pig and a part of the ambient environment, including moisture in the room air. Water fulfils a number of physiological functions necessary for life, including temperature regulation of the animal, movement of nutrients to the cells of body tissues, and playing a role in nearly every chemical reaction that takes place in the body (NRC 1998). The pig itself obtains water from three sources: drinking water; water consumed with feed (moisture content); and water formed during metabolism of the oxidation of hydrogen-containing foods. Water losses are principally through the urine, faeces, and evaporation from the respiratory tract and body surface. At the house level water enters the air by the incoming ventilation air and the evaporation of water within the room. As well, wasted water is generally captured in the slurry pit. The relative contribution of each of these different inputs and losses is highly variable, and the complex interactions between the water sources and losses are affected by differences in health status, nutrition and environment.
2.2 Water disappearance

2.2.1 Drinking motivation

While the metabolic water requirements of swine are well defined, the practical estimates of daily water intakes are less clearly understood. In addition to metabolic needs, pigs of all sizes consume water to meet a variety of needs, including physical and social. Factors such as body size, feed intake, ambient temperature, type and amount of feed ingredients and chemical substances (including medications and flavours) ingested, general state of health, stress and individual animal differences influence the pig’s absolute requirement for water. As a result, the difference between individual environmental situations and the phenotypic and motivational characteristics of the animals makes the calculation of a single water requirement figure difficult (Turner et al. 1999). It is also generally assumed that voluntary intake is a satisfactory guide to the quantity of fluid the body needs and that thirst is a sufficiently strong drive to motivate the animal to obtain the water it requires if a source is available to it. However, this is not always the case. Two factors influencing the pig’s willingness to drink include water quality and water delivery rate. Water availability, feed and ambient temperature also play important roles in determining pig water intake.
2.2.2 Water quality

When given the choice between drinking from a clean water bowl or a nipple drinker, pigs prefer to drink from a bowl (Brooks and Carpenter 1989). However, as soon as the bowl became contaminated with food from their mouths they preferred to use the nipple drinker. Ideally, water for pigs should be clean, unpolluted and with just enough mineral content to give it a good taste.

Research done by Yang et al. (1981) showed that pigs have a definite taste preference; pigs drank more sucrose solution (1% sucrose) than when they were drinking plain water, and when quinine was added to the water the pigs drank less. The authors found that pigs drank extra water to compensate for lack of food.

2.2.3 Water delivery systems

Water may be provided to pigs by several means, including nipple drinkers and wet/dry feeders. Nipple drinkers are valve drinkers that require the pig to open the valve and drink directly from the device. Pigs only need to move the activating ‘nipple’ to one side and water will flow. Several factors affect the pig water intake using a nipple drinker, including the water delivery rate, group size, number of drinkers per pen and the location and position of the drinker within the pen.
Wet/dry feeders allow the pig to select its own, preferred, water to feed ratio by providing a valve drinker in the feeder. Water use with wet/dry feeders is reduced by 10-15% compared with a dry feeder and bowl (van Cuyck 1992). As well, wet/dry feeders increase consumption of meal feed by approximately 5% compared with dry feeders and a separate nipple drinker (Gonyou 1996).

Gonyou (1996) provides a summary of other water delivery systems available for swine operations, including liquid or wet feeding, trough drinkers and bowl drinkers. Liquid feeding mixes water and feed prior to presentation to the pig. Trough drinkers allow pigs to drink from a pool of water and provide sufficient space for several pigs to drink at once. Bowl drinkers also allow pigs to drink from a pool of water, and allow one pig to drink at a time.

2.2.4 Water wastage

Drinker design can have a dramatic effect on the amount of water wasted both while the pig is drinking and through leakage from poorly designed drinkers between drinking events. In addition, it has been observed that pigs may use the drinker in a manner that the designer had not intended. For example, drinking pigs have been observed to take the drinker into their mouths in a manner that resulted in spillage from their mouth during drinking (Brooks 1994). As a result, it is important that the design of a less wasteful drinker include behavioural observations to ensure that the pig operates and uses the drinker in the way that the design engineer intended. The
amount of water used in an ISO may be reduced considerably by reducing water wastage due to spillage (van Cuyuk 1992).

2.2.5 Number of drinkers per pen

The general recommendation is that one nipple drinker should be provided for every 10 pigs in a pen (Gonyou 1996). However, several recommendations advise two nipples be provided per pen (Gonyou 1996; Olsson 1983). This may appear at first to be a precaution against the plugging of one drinker, but it has been found that wastage is reduced if more nipples are available for the same number of pigs. Conversely, Barber et al. (1988b) concluded that there was no significant difference in water use between one and two drinkers for groups of eight pigs. During a particular trial it was found that water consumption was more pronounced in a particular experiment where pigs were housed singly rather than in groups. It was believed that boredom played a role in influencing water intake, resulting in higher overall water consumption (McCleese et al. 1992).

2.2.6 Location and position

Olsson (1983) studied different nipple drinkers and found that locating the bite valve behind a pen partition in the dunging area of the pen reduced daily water wastage by almost 50% and improved the hygienic conditions in the pens. The height at which the drinker should be mounted depends upon its angle and the size of the pig. For drinkers pointing straight out from the wall, the pig should drink at shoulder height
(Gill and Barber 1990). If nipples are mounted downward, pigs should lift their head slightly. Positioning the valve to allow a more natural drinking posture for the pigs led to reduce water wastage, but there were plugging problems as the nipples would be pointing upward at about a 45° angle from the wall. The nipples mounted at a downward angle of 45° should be raised as the growing/finishing pigs grow. Gonyou (1996) reports two formulas for drinker height, one for downward mounted nipples and one for drinkers installed at a 90° angle. Nipples should be set at a height to accommodate the smallest pig in the pen.

2.2.7 Water delivery rate

Brumm (1992) presented data for average daily gain (ADG) and average daily feed intake (ADFI) based on different drinker flows and number of pigs per drinker. They found that behaviour, as measured by nipple contact time, is altered as flow rate changes. Barber et al. (1988b) found that there was a significant difference in water use between high and low delivery rates but not between one and two drinkers. There were also no significant treatment differences for mean daily live-weight gain or food conversion ratio. However, water use at 900 mL/min was 105% greater than that at 300 mL/min. They also noted that apparent drinking time at the lower delivery rate was significantly greater than at the higher rate. The same authors report that the pigs on the most restricted water delivery rate were not prepared to extend their drinking time in order to obtain a greater water intake. Consequently, at lower flow rates the pigs will consume less water, which in turn affects their performance.
On the other hand, water use, and presumably water wastage, increases with flow rate (Barber et al. 1989). Flow rates higher than the pig’s maximum rate of drinking result in water spillage and discourages pigs from drinking, but little is known about maximum intake rates. Even at flow rates below maximum intake rates, wastage would be positively related to flow rate, as spillage during accidental activation would be higher with fast flowing nipples. Barber et al. (1988b) found that increasing the water delivery rate from 300 to 900 L/min for a pen of eight pigs increased water intake by 80%. In this study more water was used, but it is not clear whether this represented additional consumption. There was no beneficial effect on pig performance with this apparent increase in water intake. Based on these studies, it would appear that minimal flow rates should be used, provided feed intake and gain are not affected. However, the level at which flow rate affects intake and gain differs among reports. The most common nipple drinker flow rates for grower/finisher pigs range from 600 to 1000 mL/min.

2.2.8 Water and feed availability

Results from a study by Barber et al. (1989) suggest that the availability of water influences the amount of water the pig consumes, which in turn affects its voluntary food intake and subsequent performance. Yang et al. (1981) suggested that the pig has a requirement for total volumetric intake and that the water to feed ratio would be minimised when the pig was fed ad libitum. That is to say the pig would limit its water intake to the minimum needed to maintain homeostasis with respect to
metabolic end products, and would maximise feed intake. Yang’s studies also suggested that when feed intake was restricted, the pig would increase water intake to satisfy its demand for gut fill.

Because of individual biological variation and the additive nature of the factors increasing water demand, it is impossible to anticipate water demand accurately and provide a water-to-feed ratio that can be guaranteed to satisfy the animal’s needs. Consequently, Brooks et al. (1989) recommended that pigs should always have access to an unrestricted supply of water.

2.2.9 Feed

In general, pigs tend to drink up to about three times as much water as the dry weight of food eaten. Yang et al. (1981) found that when feed intake is increased, the water intake also increased, indicating that pigs will overdrink water for the total needs of hydromineral balance. Yang et al. (1981) and Yang et al. (1984) also found that reducing feed gradually or suddenly results in an increase in water consumption. This is believed to be due to a desire for abdominal (gut) fill. As well, if water intake is limited, for example by low flow rates, feed intake will decrease (Brooks et al. 1989). There may be a daily volumetric limit of total dry solids and water intake, which are about 19% of an animal’s weight. The ratio chosen by pigs fed *ad libitum* thus represent the minimum water ratio for that particular food (Yang et al. 1981).

Two factors of food composition have a particular influence on water consumption, the mineral content of the diet and the quality and quantity of protein. Any amino
acids that are supplied in excess of the animal's protein requirement are deaminated and the nitrogen has to be excreted in the urine. As the pig has a limited ability to concentrate nitrogen in its urine, having extra nitrogen to get rid of means that it has to increase water intake. Consequently, if the pig is fed more protein than it can utilize for productive purposes, or an unbalanced protein, it has to increase water consumption. If dietary factors increase the water demand of the pig beyond its ability or willingness to obtain the required water intake, food intake will be depressed and performance will suffer. In addition, the pig cannot be relied upon to consume enough water to maximise biological performance. As a result, by manipulating the mineral and protein content of the diet it is possible to have a very significant effect on the biological performance, the water demand and the potential pollutant output of the pig (Brooks 1994; Brooks et al. 1989). If dietary factors increase the water demand of the pig beyond its ability or willingness to obtain the required water intake, food intake will be depressed and performance will suffer (Brooks et al. 1989).

Whether the food is presented as pellets or as a mash has an effect on weaned pig water intake. Laitat et al. (1999) reported that the difference between daily water consumption of weaned pigs given pellets and of those given meal decreased when the group size increased. The number of pigs per pen had a larger effect on the water consumption of pigs offered meal than that of pigs offered pellets. The conclusion was that pigs need more time to eat meal than to eat pellets. It is believed that pigs do not have easy access to water when eating meal in crowded conditions.
Accordingly, the number of pigs per feeder should be adapted to food presentation. Too high a number of pigs per feeder impair feeding behaviour and eventually welfare, by preventing preferential diurnal feeding activity, and this may affect productivity.

As well as affecting water consumption, the feed itself is a source of water for the pig. Moisture is inherent in the food and varies depending on the feed composition.

2.2.10 Temperature

Increased water consumption along with increased urinary water loss is an effective mechanism by which the pig can lose body heat, as urinary water absorbs body heat (Brooks et al. 1989). The extent of losses by this route depends upon the temperature of water consumed and the quantity of water consumed. Brooks et al. (1989) also found that high air temperatures increase the consumption of water per kg of food. Similarly, Ferguson and Gous (1997) reported that increasing the temperature above the thermoneutral zones results in a reduction in feed intake and decreasing the temperature below the lower critical temperature causes an increase in voluntary feed intake. As well, the temperature of the water has an impact on water consumption. Brooks and Carpenter (1990) reported that at low ambient temperatures, high water temperatures will encourage drinking behaviour whereas the reverse occurs at high ambient temperatures.
2.3 Metabolic water

When glucose is metabolised to provide energy for the body, oxygen is used to produce carbon dioxide and water. Proteins and fats are also oxidised in a similar manner to yield metabolic water (NRC 1981). The exact amount of water produced depends on the molecular weight of the substrate, but in general, carbohydrates yield about 60 g water for every 100 g of carbohydrate, and protein oxidation produces approximately 44 g of water for each 100 g of protein. The relationship is reversed when fats are oxidized; about 110 g of water are produced for every 100 g of fat. Yang et al. (1984) stated that between 0.38 and 0.48 kg of metabolic water is produced for each kg of feed consumed. Overestimation of these values is possible if care is not taken when estimating metabolic yield for water based on diet composition. According to Brooks et al. (1990), one should consider the digestibility of individual feed components rather than the diet as a whole as well as understand that a proportion of fat and protein ingested will not be oxidised but will be deposited. Research was done by Shaw (2002) to develop relationships predicting water created by metabolic reactions, as well as water retained and excreted by the pig. These relationships were derived based on the pig feed intake and feed composition, namely the amount of protein, carbohydrates and fat in the feed.
2.4 Moisture in the air

2.4.1 Moisture production of pigs

In swine the sweat glands are absent or not functional, and the lungs play an important role in the dissipation of heat. Air expired by pigs is saturated with water and is increased with physical activity and other factors that boost pulmonary exchange. These moisture losses are of considerable magnitude and are related to the environmental temperature and humidity and to the nature of the metabolism, including water intake (Maynard and Loosli 1971).

The total heat produced by animals consists of sensible heat and latent heat. Adding sensible heat to a room will increase the temperature, and adding latent heat will increase the air moisture content. Latent heat can also be represented in terms of MP. Sensible heat is lost from the body of a pig and latent heat is released through pig respiration and by evaporation from its skin. Sensible heat is converted into latent heat when water is evaporated from the pen floor (Zhang 1994; CIGR 1984).

Moisture production data in the literature date back to 1959 and changes have since taken place in animal genetics, nutrition, housing equipment and management schemes. Such changes can significantly alter the MP characteristics of the animals and their housing facilities (Xin et al. 1998). Accordingly, MP rates of pigs vary from source to source in literature. CIGR (1984, 2002) and Bond et al. (1959) offer fundamental estimations of MP at different room temperatures and different pig weights.
Moisture production data in the ASAE Standards (ASAE 2002a) are derived from animal energetics studies, excluding the moisture evaporation from litter/faeces or water spillage (Xin et al. 1998). To compensate for such shortfalls, certain empirical coefficients have been suggested to adjust the literature MP data before they are used in the design of building ventilation systems (ASHRAE 2001). However, such empirical adjustments are approximate at best because the partition of total heat production into sensible heat and MP can vary considerably among production facilities. Although MP from the animals is helpful in understanding their thermoregulation, MP including all the moisture sources in the housing system provides a much more realistic representation of the moisture load for design of the building ventilation system.

Water evaporation from wet surfaces in pig buildings is affected by many factors. Bond et al. (1965) found effects of temperature and airspeed. As well, Harman et al. (1968) reported that the mean moisture removal rates from rooms were larger for rooms with concrete floor pens as compared to rooms with partially slotted floor pens.

2.4.2 Ventilation rates

If complete details for a fan are known from a fan test, the ASHRAE fan laws (ASHRAE 1993) can be used to estimate the performance of geometrically similar fans. However, the fan laws cannot be used directly to predict airflow by a fan for
any combination of operating conditions. The fan laws predict that airflow varies linearly with fan speed, but as fan speed changes, the static pressure also changes. As a result, the fan laws do not permit the prediction of the airflow rate for changes in fan speed at a specified constant static pressure. Barber et al. (1988a) developed a mathematical model of the airflow delivered by variable-speed propeller fans. The relationship between models measuring airflow rate developed from test data and actual airflow rate conditions was analysed. They found that Equation 2.1 is expected to provide a realistic representation of a typical variable-speed fan that would be used in livestock barns:

\[ V = (b + c \cdot H) \cdot N^{1.5} \]  

(2.1)

where:

\( V \) = airflow at some static pressure (L/s),

\( H \) = static pressure head across the fan (Pa),

\( N \) = fan speed (rpm),

\( b \) = experimental coefficient, and

\( c \) = pressure coefficient.

It is unlikely that a single equation can be developed which would be accurate over the wide range of fan diameters and fan designs currently marketed for use in livestock buildings. It was concluded that fans must be chosen based on their rated performance at the expected operating pressure, not on the basis of fan diameter.
2.5 Pig water content

Another source of water is water within the pig itself. Patience and Thacker (1989) report that water makes up about 80% of the new-born piglet, while the market hog has over 50% water. Fat tissue contains very little water, so as the animal matures and body fat reserves increase, water as a proportion of total weight decreases. According to Maynard and Loosli (1971), the water content of various body parts varies greatly. Blood plasma contains 90 to 92%, muscle 72 to 78%, bone approximately 45% and the enamel of teeth 5%.

Wagner et al. (1999) developed linear and non-linear equations to investigate the growth patterns of moisture in pigs. Carcass lean and fat tissues significantly increased in lipid percentage and decreased in moisture percentage as live weight increased. Shields et al. (1983) also performed an experiment to evaluate quantitative and percentage chemical compositional changes of swine from 1.5 kg (birth) to 145 kg body weight. They indicate that water increased quadratically as live body weight increased.

Research was done at the Prairie Swine Centre Inc. (PSCI) by Cooper et al. (2001) to predict pork carcass composition in market pigs using real-time ultrasound. Part of this research included developing equations to predict the moisture content of pigs used at PSCI. This research was done for barrows and gilts from 90-120 kg. The
authors concluded that equations need to be developed independently for specific herds at specific weights for both barrows and gilts because of the differing body composition between the genders.

2.6 Manure water content

2.6.1 Faeces
The amount of faeces produced and the volume of water lost through by defication depend largely upon nutrient digestibility and feed intake. The losses through the gut vary with the nature of the diet, increasing with the level of fibre intake and intakes of other feeds that have laxative qualities. In general, the greater the proportion of undigested material, the greater the water loss (Thulin and Brumm 1991; Maynard and Loosli 1969). Archer and Nicholson (1992) reported that the variation in water intake for pigs due to type of feeding will make a difference to the quantity and dry matter content of the excreta, reporting 90% moisture content of faeces for grower-finisher pigs on dry meal feed.

2.6.2 Urine
Water is the main constituent of urine, generally contributing around 95% of the volume. The amount of water excreted in the urine is highly variable. The kidneys regulate the volume and composition of body fluids by excreting more or less water, depending on intake and output through other mechanisms and the amounts of catabolic products such as waste salts and urea, for which water serves as a solvent.
Increasing the amounts of minerals and protein in the diet proliferates the loss of water through urine, increasing the water requirement accordingly (Thulin and Brumm 1991; Maynard and Loosli 1969). In addition, when a high-protein diet is fed, there is less metabolic water formed in protein catabolism than is the case for carbohydrate or fats. This also enhances the need for increased water consumption (Brooks and Carpenter 1990). The minimum daily water requirement for eliminating these various components is difficult to assess and to predict, which is why unlimited access to water is generally recommended. ASAE (2002b) states that for every 1000-kg of live swine mass, 39 kg of urine is produced.

2.6.3 Slurry

After faeces and urine have been excreted, the amount and composition change because water is lost by evaporation and various conversions take place in the manure pit. The daily manure production for classes of swine ranging from 5-90 kg is presented in a Canada Plan Service publication (West and Turnbull 1989). For 20-90 kg pigs, the authors present an average value of 5.1 L/pig of manure produced. As well, the ASAE Handbook (2002b) offers manure production and characteristics for a range of animals, including swine. Total manure production is presented as 84 kg per 1000-kg live animal mass per day, and the total solids in the manure is 11 kg per 1000-kg live animal mass per day. Actual values vary due to differences in animal diet, age, usage, productivity and management. ASAE recommends that whenever site-specific data are available or actual sample analyses can be performed, such information should be considered.
2.7 Summary

Considerable research has been done on different sources and sinks of water in an ISO (Barber et al. 1989; Bond et al. 1964; Brooks 1994; Brooks and Carpenter 1990; Ferrell and Cornelius 1984; Fraser et al. 1990; Gonyou and Lou 1996; Schulte et al. 1990; Turner et al. 1999; Yang et al. 1981). However, no comprehensive study has been done on the water balance of a grower-finisher room as a whole, which is important to ensure that all the sources and sinks of water in an ISO are accounted for and relative contributions of each parameter are clarified.

In addition to water conservation, water in the air needs to be managed in an ISO such that condensation and frost formation does not occur in the room to minimise damage to ventilation equipment. This is especially true in winter conditions when the air exchange rate in the room is low in an attempt to minimise the need for supplemental heating. Equations are available to predict the MP within the room (Bond et al. 1959; CIGR 1984; CIGR 2002). However, a literature review revealed that the equations presently used to predict MP of animals underestimate the actual current MP of animals, including swine and poultry (Harmon et al. 1997; Xin et al. 2001). As a result, comparing measured MP values with predicted MP in a typical building setting would indicate how suitable the equations are for design purpose.
2.8 Objectives

Based on past research on the different sources and sinks of water in an ISO, it is apparent that there are a large number of factors affecting the sources and sinks of water in a grower-finisher room. By measuring the complete water balance of a grower-finisher room it will be possible to identify the significant sources and sinks of water, so that future research on water conservation in an ISO may focus effectively on significant areas. As well, verifying the use of various MP equations is important to ensure proper design of ISO ventilation systems.

The objectives of this research was twofold:

1. To measure and compare the water balance of grower-finisher rooms using dry and wet/dry feeders.
2. To compare measured MP values with various MP prediction equations.
3.0 ESTABLISHING AND COMPARING THE WATER BALANCE OF GROWER-FINISHER ROOMS USING DRY AND WET/DRY FEEDERS

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3.1 Introduction

Intensive swine operations use large volumes of water, creating great demands on the water source. Although wasted water does not increase the quantity of nutrients and other potential contaminants in the manure, it does increase the volume of slurry, which amplifies the costs for manure storage, transport and processing.

Use of wet/dry feeders have been shown to reduce water usage as compared to dry feeders by 10-15% (van Cuyck 1992). Dry feeders employ nipple drinkers, which are valve drinkers that require the pig to open the valve and drink directly from the device with spillage going directly to the floor. Wet/dry feeders provide a valve drinker in the trough of the feeder, where the pig can mix their feed with water, and
most of the spilled water is collected in the trough. Wet/dry feeders increase consumption of meal feed by approximately 5% compared with dry feeders and a separate nipple drinker (Gonyou 1996).

In the past, various components of the water balance of a grower-finisher room have been measured, but not comprehensively and/or comparatively (Aarnink et al. 1992; ASAE 2002b; Brooks and Carpenter 1990; Cooper et al. 2001; Fraser et al. 1990; Shaw 2002; van’t Klooster and Greutink 1993). The amounts of water pigs drink, how much manure they produce, the moisture content of their feed, the amount of water evaporated from both the pigs and the room, the amount of water within the pig and the amount of water created through metabolism is generally known. However, a comprehensive summary and measurement of the water balance of a grower-finisher room has not been considered to evaluate the impact of each input and output on the water balance.

Brooks and Carpenter (1990) present an example of a water balance for a 60-kg pig, where the pig was the control volume, not the room. They present estimated values for water used/lost by the pig through growth, respiration, skin, faeces and urine; and water consumed/formed by the pig through food water, food oxidation and water consumed. Feeder type was not a factor in this water balance, and it is unknown how much spillage may be expected in this balance, as well as moisture contributed to the room air.
The moisture balance of a grower-finisher pig building with deep litter was determined by van't Klooster and Greutink (1993) to determine the minimum ventilation rate required to remove the MP. When moisture from urine and faeces enters the sawdust, composting of the litter occurs and water is created, which is added to the ambient air of the pig house. The authors considered water and feed intake, moisture retained by the pig, metabolic water produced by the pig, water produced by latent heat production, and water removed as urine and faeces.

As reported by Fraser et al. (1990), an animal’s water intake varies widely depending on environmental temperature and quantity and quality of feed consumed. Water intake appears to increase with increasing solid food intake, percentage of protein in the diet, and mineral content of the diet, specifically the sodium and potassium levels (Brooks and Carpenter 1990; Fraser et al. 1990).

When fat, protein and carbohydrates are metabolised to provide energy for body processes, water is formed. As described by Schiavon and Emmans (2000), the water arising from the oxidation of protein, fat, and carbohydrate can be approximated by stoichiometry of their respective reactions. Generally, protein yields 0.48 kg water per kilogram of protein metabolised, fat yields 1.10 kg water per kilogram of fat metabolised, and carbohydrates yield 0.60 kg water per kilogram of carbohydrate metabolised (Patience and Thacker 1989). Some of the protein, fat and carbohydrates are excreted in the faeces, some are retained by the pig and some are metabolised, producing water (Shaw 2002). Yang et al. (1984) state that between
0.38 and 0.48 kg of total metabolic water is produced for each kilogram of feed consumed. Brooks and Carpenter (1990) caution against use of this simple ratio, as this may overestimate the yield of metabolic water due to different diet compositions. Recent research done by Shaw (2002) revealed the proportions of protein, fat, and carbohydrates excreted in the faeces and retained by the pig so the amount of nutrients available for catabolic reactions may be determined.

Aarnink et al. (1992) derived a mathematical model to estimate the amount of slurry produced by fattening pigs. Several of their parameters, including water excreted by the pig, water evaporated by the animal and water retained by the pig, were estimated values using equations and relationships derived by other authors and not actual measurements by the author.

ASAE (2002b) predicts that 11 kg of solids and 84 kg of total manure per 1000-kg live animal mass is produced on a daily basis. These predictions do not account for differences in animal diet, age, growth rate and management. When site-specific data is available, such information should be considered and not the values presented in the standard. As well, Brooks and Carpenter (1990) state that the amount of faeces produced and the volume of water lost through this route depend upon nutrient digestibility and feed intake. Therefore, unless the diets are presented in the literature, it may not be suitable to extract data from other work to predict the amount of water contributed to the room by faeces. The same authors report that urinary water loss is largely dependent on the amount of water ingested.
Values predicting MP by swine are presented in ASAE (2002a) and Zhang (1994). As an example, for a 20 kg pig at 20°C, 3.7 g kg⁻¹ hr⁻¹ of water is produced, and for a 100 kg pig at 20°C, 1.2 g kg⁻¹ hr⁻¹ of water is produced. However, these values are collected based on data and equations derived by Bond et al. (1959) and may not be suitable for current pig genetics and barn management practices. CIGR (2002) also provide equations to predict MP of swine but does not mention feeder type as a possible factor in MP.

Because fat holds very little water, and the fat content of the pig increases as the pig ages, the percent of water content of the pig decreases over time (Patience and Thacker 1989). Equations predicting the water content of finisher pigs were developed by Cooper et al. (2001) and were determined by grinding and lyophilizing pig carcasses to determine water content. However, the same author reports that the water content of the pig is dependent upon its protein content, size, sex, and genetics. Shields et al. (1983) present water as a percent of the empty body weight from birth to 145 kg.

3.2 Objectives and expected benefits

The objectives of this study were to measure the water balance of a grower-finisher room and to compare the impact of dry and wet/dry feeders on the water balance. A better understanding of the partitioning of water entering and leaving the grower-
finisher room would be useful to identify possible water savings. Further studies may be initiated to reduce water usage at the significant sources. The major water outputs may also be studied and recycling of the water at these sources considered. As well, it is expected that obtaining the water balance of two rooms with similar conditions but with different feeder type will yield a feeder with higher water savings. This reduction in water usage would mean less demand on the water source and less slurry produced, representing savings for the pork producer.

3.3 Water balance components

A water balance of a room may be described as where the total water input into the room equals the total water output of the room. As seen in Fig. 3.1, the water balance of a grower/finisher room includes all the sources of water entering and leaving the room. The water enters the room through the drinkers, in the feed, as water produced through metabolic reactions, as water in the pig and as moisture in the air ventilated into the room. The water then leaves the room through the slurry, as water in the pig and also as water in the air ventilated outside. The water balance can be summarised by Eq. 3.1, which is a steady-state mass balance:

\[ W_{\text{drinker}} + W_{\text{feed}} + W_{\text{met}} - W_{\text{slurry}} - \Delta W_{\text{pig}} - \Delta W_{\text{vent}} = 0 \]  \hspace{1cm} (3.1)
where:

\[ \Delta W_{\text{vent}} = W_{\text{vent out}} - W_{\text{vent in}} \]  

(3.2)

and:

- \( W_{\text{drinker}} \): water disappearance from drinker (kg·pig\(^{-1}\)·day\(^{-1}\)),
- \( W_{\text{feed}} \): feed water content (kg·pig\(^{-1}\)·day\(^{-1}\)),
- \( W_{\text{met}} \): water produced through metabolism (kg·pig\(^{-1}\)·day\(^{-1}\)),
- \( \Delta W_{\text{pig}} \): difference in water content of pig at beginning and end of cycle (kg·pig\(^{-1}\)·day\(^{-1}\)),
- \( W_{\text{slurry}} \): water in slurry (includes faeces, urine and spillage) (kg·pig\(^{-1}\)·day\(^{-1}\)),
- \( W_{\text{vent in}} \): water in through ventilation (kg·pig\(^{-1}\)·day\(^{-1}\)), and
- \( W_{\text{vent out}} \): water out through ventilation (kg·pig\(^{-1}\)·day\(^{-1}\)).
3.4 Materials and Methods

3.4.1 Animals and housing conditions

Two commercial rooms with partially slatted floors at PSCI, Saskatoon, SK were used over three split production cycles for a total of six trials, with each trial considered as a block. One room was equipped with dry feeders and nipple drinkers in each pen, and the other room had a wet/dry feeder in each pen with no additional water source. Each room contained 6 pens of 12 pigs, half barrows and half gilts, for a total of 72 animals per room. The pigs were randomized and moved into the pens on the first day of each trial so the pens had even weight. Pigs entered the rooms at a mean body weight of 21.1±0.1 kg and remained in the rooms for 14 weeks. The pigs were manually ad lib fed normal PSCI pelleted diets on a daily basis and feed weight was recorded for each feeder. Two different feeds were used, one for the grower...
phase and one for the finisher phase. The metabolizable energy of the grower feed was 3.15 Mcal/kg with 19.1% crude protein, and the metabolizable energy of the finisher feed was 3.25 Mcal/kg with 15.6% crude protein. The pigs had unlimited access to water and feed and were checked daily for health status and, if necessary, treated accordingly to normal PSCI procedures.

The rooms used for this study were mirror images of each other, side by side on the east-west direction and considered exposed to similar ambient conditions with one north exterior wall per room and one south wall facing the common hallway. The rooms were 5.3 m x 14.3 m with partially slatted floors. Each pen measured 1.98 m x 4.12 m with slatted floor on a length of 1.83 m. The manure pits ran the full length of the room and had a plug on both ends of the manure pit, which were alternately pulled to drain the pits. For each trial the manure pits in both rooms were managed similarly. Each pit was power washed before each cycle to ensure similar starting conditions. If one manure pit was full and needed to be emptied, then the other pit was also emptied. As well, if excessive spillage occurred within one of the rooms and the manure pit was emptied, the manure pit in the other room was also emptied. Scraping of the pens was performed to remove excess manure if needed, and each scraping event was recorded. The rooms were on a 12-hour lighting cycle, where the lights would turn on at 07:00 and would turn off at 19:00.

The rooms used a negative pressure ventilation system for air exchange equipped with a proportional-integral-derivative controller (PID) for both rooms. There were
three fans in each room: stage-1 and stage-2 fans being variable speed propeller fans (J12 and NW2K, respectively, Delair Systems Ltd., Humboldt, SK, Canada) and the stage-3 fan was a single speed fan (J24, Delair Systems Ltd., Humboldt, SK, Canada). During the winter experimental period, the stage-2 and stage-3 fans were not required and were disabled and sealed. The minimum ventilation rate was adjusted so it remained within a comparable range in both the control and treatment rooms. The temperature set point was the same for both rooms, and the controllers were set to gradually decrease the temperature set point from 21°C at 25 kg to 15°C at 75 kg. This temperature strategy was derived from recommendations by different authors, including Zhang (1994). Each room was equipped with six identical air inlets. The room had a natural gas heater (ATL-1200, L-B White, WI, USA, 18 kW), and a recirculation duct that ran the length of the room.

The dry feeders were located at the front of the pen, and the nipple drinkers were installed over the slats. The wet/dry feeders were installed in front of the slats inside the pens. Both feeders were set up so the pig would stand parallel with the pen wall when feeding. Following Gonyou (1996) recommendations, the drinker height was adjusted to 5 cm above the back of the smallest pig in the pen as the pigs grew to help minimize water wastage and the drinker flow was verified for each drinker to ensure the flow rate was between 500-750 mL/min.
3.4.2 Experimental design

Wet-dry feeders were used for one room and dry feeders were used in the second room. After the first six weeks of the grower cycle the feeders were swapped between the two rooms to minimise the room effect and to observe the effect of feeder type on the same pigs. After swapping the feeders, two weeks were allocated to allow the pigs to become acclimatised to the new feeders, and after two weeks measurements began for the finisher phases. Three repetitions of each of the following combinations were obtained: grower and dry feeders; grower and wet/dry feeders; finisher and dry feeders; and finisher and wet/dry feeders.

3.4.3 Statistical analysis

A randomised complete block design (RCBD) was used to analyse the water balance of the two grower-finisher rooms over six separate grower and finisher production periods. Statistical analysis using GLM in SAS was done to determine the effect of feeder type on each parameter in the water balance. An initial analysis revealed that the grower and finisher phases had significant differences for all measurements in the water balance, so the analysis was separated for the grower and finisher phases. The room effect was also investigated, and was found to be not significant \((p>0.05)\) and was removed from the model. Table 3.1 is a summary of the final sources of variation for the statistical model.
Table 3.1: Sources of variation for the grower and finisher phases in the water balance experiment.

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>Degrees of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
</tr>
<tr>
<td>Block</td>
<td>2</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
</tr>
</tbody>
</table>

3.5 Data collection

Each water input and each water output as defined in Fig. 3.1 was measured for each trial. Trial 1 began on October 16th, 2000 and Trial 6 ended on September 25th, 2001. The measurements were taken over six weeks and reinstated with the beginning of the following trial. A two-week downtime between each trial was used to switch the feeders between the two rooms and ensure all the instruments were in proper working order.

3.5.1 Water disappearance

Pigs obtained their drinking water through a single drinker per pen in each room. Each room had four water meters (Model C700, ABB Water Meters, Inc., Florida, ±5%) to measure water disappearance (WD) from the drinkers. One water meter was hooked up to the main water line within the room to measure total water flow into the room. The remaining three water meters were used to monitor the water flow for randomly selected individual pens. The volume of water running through each water
meter appeared on the register and was manually recorded daily throughout each trial.

3.5.2 Feed moisture

For each feed type a sample was obtained and a 5 g sample was dried at 105°C for 24 h in the PSCI lab to determine the moisture content of the feed (ASAE 2002c). The daily feed intake was multiplied by the moisture content and the average daily moisture input into the rooms by the feed was determined.

3.5.3 Metabolic water

According to Shaw (2002), the amount of water created through metabolic reactions of protein is determined by the following series of equations:

\[
P_{in} = ADFI \cdot \text{CP} \quad (3.3)
\]

\[
P_{faeces} = P_{in} \cdot (0.12)(88\% \text{ digestibility}) \quad (3.4)
\]

\[
P_{retained} = P_{in} \cdot \text{PR} \quad (3.5)
\]

\[
P_{catabolic} = P_{in} - P_{faeces} - P_{retained} \quad (3.6)
\]

\[
P_{metabolic} = P_{catabolic} \cdot 0.48 \quad (3.7)
\]

where:

\[
P_{in} = \text{protein into the pig via feed (kg·pig}^{-1} \cdot \text{day}^{-1}),
\]

\[
ADFI = \text{average daily feed intake (kg·pig}^{-1} \cdot \text{day}^{-1}),
\]
CP = crude protein in the feed (%),
P_{faeces} = protein lost in the faeces (kg· pig\(^{-1}\)· day\(^{-1}\)),
P_{retained} = protein retained in the pig (kg· pig\(^{-1}\)· day\(^{-1}\)),
PR = protein retained by the pig (%, 0.509),
P_{catabolic} = protein available for metabolic reactions (kg· pig\(^{-1}\)· day\(^{-1}\)), and
P_{metabolic} = water created from metabolic reactions of protein (kg· pig\(^{-1}\)· day\(^{-1}\)).

A similar procedure is done for the fat metabolic water. Since fat and carbohydrates are not retained by the pig, unlike protein which is retained by the pig, the amount of water created through metabolic reactions of fat is determined by the following series of equations:

\[ F_{in} = \text{ADFI} \cdot \text{CF} \quad (3.8) \]
\[ F_{faeces} = F_{in} \cdot (0.12)(88\% \text{ digestibility}) \quad (3.9) \]
\[ F_{catabolic} = F_{in} - F_{faeces} \quad (3.10) \]
\[ F_{metabolic} = F_{catabolic} \cdot 1.1 \quad (3.11) \]

where:

\[ F_{in} = \text{fat into the pig via feed (kg· pig\(^{-1}\)· day\(^{-1}\))}, \]
\[ \text{CF} = \text{crude fat in the feed (%)}, \]
\[ F_{faeces} = \text{fat lost in the faeces (kg· pig\(^{-1}\)· day\(^{-1}\))}, \]
\[ F_{catabolic} = \text{fat available for metabolic reactions (kg· pig\(^{-1}\)· day\(^{-1}\))}, \]
\[ F_{metabolic} = \text{water created from metabolic reactions of fat (kg· pig\(^{-1}\)· day\(^{-1}\))}. \]
For the carbohydrates, the following series of equations is used to calculate metabolic water produced from carbohydrates:

\[ C = 100 - (CP + CF + \text{ash}) \]  
\[ C_{\text{in}} = \text{ADFI} \cdot C \]  
\[ C_{\text{faeces}} = C_{\text{in}} \cdot (0.12) \]  
\[ C_{\text{catabolic}} = C_{\text{in}} - C_{\text{faeces}} - C_{\text{retained}} \]  
\[ C_{\text{metabolic}} = C_{\text{catabolic}} \cdot 0.6 \]

where:

- \( C \) = carbohydrates in the feed (%),
- \( \text{ash} \) = ash in the feed (%),
- \( C_{\text{in}} \) = carbohydrates into the pig via feed (kg· pig\(^{-1}\)· day\(^{-1}\)),
- \( C_{\text{faeces}} \) = carbohydrates lost in the faeces (kg· pig\(^{-1}\)· day\(^{-1}\))
- \( C_{\text{retained}} \) = carbohydrates retained by the pig (kg· pig\(^{-1}\)· day\(^{-1}\)),
- \( C_{\text{catabolic}} \) = carbohydrates available for metabolic reactions (kg· pig\(^{-1}\)· day\(^{-1}\)), and
- \( C_{\text{metabolic}} \) = water created from metabolic reactions of carbohydrates (kg· pig\(^{-1}\)· day\(^{-1}\)).

The feed used in this experiment was analysed for protein, fat, and ash content, from which the carbohydrate content could be determined. The total metabolic water is the addition of the metabolic water created from these feed components. Metabolic
water was calculated using the equations and the results using equations from Shaw (2002) were compared to the results obtained by Yang et al. (1984).

3.5.4 Manure water

The total water output in the manure was obtained by measuring the volume of manure deposited in the channels and determining its moisture content. As the manure channels were not geometrically rectangular, the channels were calibrated to obtain proper volumes. Prior to calibrations, the manure channels were cleaned with power washing, leaving a few centimetres of water in the channels as a baseline for measurements. Measurements of the water depth were taken at three locations of the manure channel to determine the baseline for measurements. A known volume of water was subsequently deposited into the manure channels (e.g. 3 m³), with measurements being taken for the three same locations for different increments of water volume. Using this data, calibration curves were plotted for each of the three location in the manure channel as in Fig. 3.2. The data was plotted and a regression line was calculated to determine the calibration curve for that spot. Four separate calibrations for each channel were done to verify the calibration curve. Throughout the experiment, three times a week a yardstick was inserted in the manure channel in the same three locations as on the calibration curve to measure the manure depth. An apparatus was built to ensure the yardstick was placed in the exact same spot with the exact same slope to ensure consistency of the measurements. Using the calibration curve, the depth of manure was associated with the volume of slurry in the pit.
For each sampling event, three samples of the slurry were obtained from each manure channel and a sub sample was obtained to analyse the moisture content. After removing the manure slat at one position, a plastic cylinder, which was a large plastic bucket with the bottom cut off, was lowered into the pit and was kept secure at the bottom. A large electric paint stirrer was then used to mix the manure contained in the cylinder, and a sub sample was taken with a clean 10-L plastic pail. This operation was repeated at two other locations. The sub samples taken from all three locations were combined and briefly stirred with the paint stirrer. A final sample from the sub samples was taken and transferred into plastic jars. The jars were transferred to a commercial laboratory (EnviroTest Laboratories, Saskatoon, SK) for moisture content analysis. For the first three weeks of the experiment, the moisture content of a representative sample of manure was obtained on a weekly basis.
basis. Since the weekly moisture content of the samples for the first three weeks were within ±2%, the manure was then sampled only prior to pit drainage. If the manure pits were to be drained when the experiment was ongoing, a second sample was taken after the pit has been drained to determine the remaining moisture content for the manure pit.

3.5.5 Pig performance and water content

The water retained by the pigs was determined by measuring the difference in water content of the pigs at the end and beginning of each trial. A relationship between the fat thickness, muscle tissue thickness, pig weight, and pig water content was derived by Cooper et al. (2001) and was used to determine the water content of the pigs in the experiment. These derived relationships were meant only for pigs at weights above 110 kg, but due to lack of other prediction equations these relationships were used for all the pig weights in the study. Each pig was weighed at the beginning and end of each trial to determine pig performance. The starting and ending day for each trial was used to weigh all the pigs and to perform real-time ultrasound measurements to determine the fat and muscle tissue thickness on a selected group of 20 pigs; a representative sample of 10 pigs per room was used.

3.5.6 Ventilated water

Moisture is added to the air within the room through evaporation from the pigs and the floor. The difference in the moisture content of the air leaving and entering the
room was measured to determine the moisture content added to the air. The outside air temperature and relative humidity were measured with an integrated sensor (model MRHT-3, General Eastern Instruments, RH accuracy ±3%, temperature accuracy ±0.5°C). Room air temperatures were measured with a type T thermocouple (±0.5°C), and the room relative humidity were evaluated with bulk polymer humidity sensors (Rotronic, General Eastern Instruments, ±2%). Fan performance curves were developed based on fan performance data from Prairie Agricultural Machinery Institute (PAMI 1989a; PAMI 1989b) and estimation equations provided by Barber et al. (1988). These performance curves were then used to determine the volume of air entering and leaving the room by calculating the ventilation rate using the static pressure difference across the room and the rotation speed of each fan. Static pressure transducers (model 264, Setra Systems, Toronto, Canada, ±1%) estimated the static pressure and proximity sensors (model SR3, Microswitch, ±3%) were used to measure the fan rotation speed. A data logger system (Datataker DT 100, Data Electronics (Aust.) Pty. LTD., Australia) measured the output from all the sensors every minute and recorded an averaged value on a 15-minute basis. Data was downloaded from the data logger three times a week. The inside temperature and relative humidity measurements were compared with reference instruments (mercury thermometer ±0.5°C and psychrometer ±3%) three times a week. The controller sensor accuracy was evaluated in both rooms.

To determine mass flows of water removed by ventilation, the psychrometric properties of the inside and outside air were calculated using equations given by
Moisture production was calculated at 15-min intervals by solving the following steady-state equation:

\[ MP = \frac{V \cdot (W_e - W_o)}{\nu} \]  
(3.17)

where:

- \( MP \) = moisture production rate, kg/s,
- \( V \) = ventilation rate, m\(^3\)/s,
- \( W_e, W_o \) = humidity ratio of exhaust and outside air, respectively, kg water/kg dry air,
- \( \nu \) = specific volume of air, kg dry air/m\(^3\).

### 3.6 Water balance

The water balance was calculated using Eq. 3.18, which is the same as Eq. 3.1, but with the addition of an error term:

\[ W_{drinker} + W_{feed} + W_{metabolism} - W_{slurry} - \Delta W_{pig} - \Delta W_{ventilation} = \text{Error} \]  
(3.18)

The water balance was averaged over three trials for grower and finisher phases and the results are presented as kg pig\(^{-1}\) day\(^{-1}\). All terms of the water balance have been
measured, except for the error term, which was included in the water balance to account for any discrepancies in the measurements.

3.7 Results and Discussion

Data was collected for the water balance study over the course of 11 months. The dates used for this experiment are outlined in Table 3.2.

Table 3.2: Dates for water balance study.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Start Date</th>
<th>Finish Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>October 17, 2000</td>
<td>November 28, 2000</td>
</tr>
<tr>
<td>2</td>
<td>December 12, 2000</td>
<td>January 23, 2001</td>
</tr>
<tr>
<td>3</td>
<td>February 12, 2001</td>
<td>March 26, 2001</td>
</tr>
<tr>
<td>4</td>
<td>April 10, 2001</td>
<td>May 22, 2001</td>
</tr>
<tr>
<td>5</td>
<td>June 19, 2001</td>
<td>July 31, 2001</td>
</tr>
<tr>
<td>6</td>
<td>August 14, 2001</td>
<td>September 25, 2001</td>
</tr>
</tbody>
</table>

3.7.1 Data processing

The data was processed to remove spurious data from the analysis. Instances arose where drinker leakage occurred in the wet/dry feeder, where the nipple had feed caked around the nipple and was held open. This occurred three times over 11 months, and the data was adjusted so ideal conditions using the wet/dry feeder could be studied. When this happened, the data was analysed to note periods where leakage occurred. These periods were either removed from the dataset, or the data was corrected based on conditions in other pens, along with removing the wasted water from the manure pit. Other data processing included removal or correction of periods where incorrect measurements were taken or recorded, including static
pressure measurements and fan speed measurements. The final datasets were compiled so the same weights were compared for the different trials.

Due to unforeseeable conditions, for the last four cycles the outside relative humidity data that was measured at PSCI was much less than what was expected. As a result, the outside relative humidity data was verified and corrected based on data collected by Environment Canada at a weather station near PSCI.

The statistical analysis revealed significant differences between each of the measured variables for grower and finisher trials. As a result, the data were separated into grower and finisher trials and analysed separately. On each graph presented G1, G2, and G3 represent the grower phases and F1, F2, and F3 represent the finisher phases for experiments 1, 2 and 3, respectively.

3.7.2 Pig performance

Tables 3.3 and 3.4 summarize the starting and ending weights for each trial, as well as the ADG for each trial. The ADG values presented in Tables 3.3 and 3.4 are for the pig performance over the entire trials. The average ADG for the three grower trials G1, G2, and G3, on dry and wet/dry feeders were 0.77 and 0.79 kg/day, respectively. For finisher pigs in F1, F2, and F3 on dry and wet/dry feeders, the average ADG were 0.93 and 0.96 kg/day, respectively. Gonyou (1996) presented an ADG for a complete grower/finisher cycle across all feeders, which was 0.90 kg/day, which compares to the average of the ADG measured for this experiment, which was
0.86 kg/day. Gonyou (1996) used a mash diet instead of a pelleted diet, which was used in this study and may be why a small difference in ADG is seen.

Table 3.3: Average pig performance for grower phase for pigs on both dry and wet/dry feeders. No significant differences were seen between pigs on dry and wet/dry feeders.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Starting weight (kg)</th>
<th>Finishing weight (kg)</th>
<th>ADG (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry*</td>
<td>Wet/Dry*</td>
<td>Dry</td>
</tr>
<tr>
<td>G1</td>
<td>23.3</td>
<td>23.4</td>
<td>56.3</td>
</tr>
<tr>
<td>G2</td>
<td>24.7</td>
<td>24.7</td>
<td>58.0</td>
</tr>
<tr>
<td>G3</td>
<td>17.5</td>
<td>17.6</td>
<td>47.0</td>
</tr>
<tr>
<td>Average</td>
<td>21.8</td>
<td>21.9</td>
<td>53.8</td>
</tr>
</tbody>
</table>

* Dry: dry feeder; Wet/Dry: wet/dry feeder.

Table 3.4: Average pig performance for finisher phase for pigs on both dry and wet/dry feeders. No significant differences were seen between pigs on dry and wet/dry feeders.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Starting weight (kg)</th>
<th>Finishing weight (kg)</th>
<th>ADG (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry*</td>
<td>Wet/Dry*</td>
<td>Dry</td>
</tr>
<tr>
<td>F1</td>
<td>70.0</td>
<td>69.6</td>
<td>109.5</td>
</tr>
<tr>
<td>F2</td>
<td>69.8</td>
<td>70.0</td>
<td>107.7</td>
</tr>
<tr>
<td>F3</td>
<td>58.1</td>
<td>58.9</td>
<td>99.3</td>
</tr>
<tr>
<td>Average</td>
<td>66.0</td>
<td>66.2</td>
<td>105.5</td>
</tr>
</tbody>
</table>

* Dry: dry feeder; Wet/Dry: wet/dry feeder.
For grower pigs wet/dry feeders increased ADG by 1 to 5%. For finisher pigs, the ADG either was the same or was improved by up to 7% with wet/dry feeders compared to dry feeders. This is comparable to the results from Gonyou (1996), where the difference in ADG was improved by 5% for pigs on wet/dry feeders. However, statistical analysis shows no significant difference between the ADG of the pigs on wet/dry feeders versus dry feeders (p>0.05). It should be noted that the pens were of mixed gender, so the weight gain represents the average of barrows and gilts. Due to availability of pigs at the time of the third experiment, the starting weight was lower than for the first two experiments.

3.7.3 Feed

The average daily feed intake (ADFI) in kg of feed per pig per day is presented in Fig. 3.3. As with the pig performance, the ADFI is based on results from the entire trials. The ADFI for grower pigs was 1.8 and 1.9 kg/day for dry and wet/dry feeders, respectively, and for finisher pigs the ADFI was 3.1 and 3.4 kg/day for dry and wet/dry feeders, respectively. These ADFI values are comparable to results from Gonyou and Lou (1996), who report an overall average of 2.74 kg/day for feed disappearance for the entire grower-finisher trial, combining the results from both dry and wet/dry feeders. The overall average for this study was 2.55 kg/day. The ADFI was generally higher for pigs on wet/dry feeders by about 5% as compared to the pigs on the dry feeders. This is consistent with results presented by Gonyou (1996). However, there is no significant difference in ADFI (p>0.05) between feeder
types. The error bars in Fig. 3.3 represent the error of the feed cart measurements (±0.5 kg).

![Graph showing ADFI for trials](image)

Figure 3.3: Average daily feed intake (ADFI) for all trials in kg·pig⁻¹·day⁻¹.

The feed conversion (FC) for pigs in each trial is presented in Fig. 3.4. Again, the FC is based on results from the entire trials. The average FC for grower pigs was 2.6 and 2.5 kg<sub>feed</sub>/kg<sub>pig</sub> for dry and wet/dry feeders, respectively, and for the finisher phase the FC was 3.7 and 3.6 kg<sub>feed</sub>/kg<sub>pig</sub> for dry and wet/dry feeders, respectively. There was no statistical difference in feed conversion for pigs on dry or wet/dry feeders (p>0.05), which is also consistent with results presented by Gonyou (1996).

In Fig. 3.4, the error bars include both the error terms for the feed cart scale and the weigh scale for the pigs, which was also ±0.5 kg.
Figure 3.4: Average daily feed conversion (FC) for all trials in kg feed/kg gain.

3.7.4 Water disappearance

Figure 3.5 presents the summary of the water disappearance (WD) for the three trials, which was edited to include all viable datasets for the water balance. For grower pigs, the average WD of the three trials was 6.0 and 5.4 kg·pig⁻¹·day⁻¹ for dry and wet/dry feeders, respectively. For finisher pigs, the average WD was 9.3 and 6.2 kg·pig⁻¹·day⁻¹, respectively, which is a 34% reduction in WD. For the entire grower-finisher cycle, there was a 24% reduction in WD, or 1.9 kg·pig⁻¹·day⁻¹. The difference for WD between feeder types for grower pigs was not significant (p>0.05), but for finisher pigs the difference was significant (p<0.05). Brooks and Carpenter (1990) suggested that a 60 kg pig would have a WD of 4.3 kg/day,
assuming no spillage. Similarly, for pigs ranging from 17 to 74 kg of live animal weight, fed various amounts of feed and kept at various environmental temperatures, Schiavon and Emmans (2000) observed an average of 4.9 kg·pig⁻¹·day⁻¹ for water intake, also assuming no spillage. If these values are compared with the current measured values of WD from the wet/dry feeders, the measurements for this experiment were higher. van’t Klooster and Greutink (1993) do not present average values of WD for their study, but graphs were presented which included the WD over the course of the study. These values were extracted and averaged, and the average WD for the grower-finisher cycle was 4.5 kg·pig⁻¹·day⁻¹, which was also lower than what was measured for this experiment. These differences may be due to a number of factors, including differences in feed composition, ambient temperature, or flow rate of the drinkers. Comparing the same predicted values with results from the dry feeders, the average measured value from the dry feeders is much higher. Since these predicted values are the actual water intake of the pig, much of the difference seen on the dry feeder may be associated with spillage. Thulin and Brumm (1991) also present values for estimating ad libitum drinking for pigs from 30-50 kg, which was 8 kg·pig⁻¹·day⁻¹, and for pigs from 50-110 kg, which was 16 kg·pig⁻¹·day⁻¹. These values are higher than what was measured in this experiment, but since these values were for planning purposes there may have been a safety factor increasing the amount of water actually consumed by the pigs to ensure adequate water was available to the pigs.
Finisher pigs tend to drink more water than grower pigs, which is reflected in the results for both feeder types as shown in Fig. 3.5. Since the difference in pig performance was not statistically different for pigs on dry or wet/dry feeders, we may conclude that the extra WD seen with the dry feeders as compared to the wet/dry feeders is likely due to spillage and not because the pigs drank more water. The error bar considers the error of the water meters, which was ±5%.

Some problems were encountered, such as compaction of feed within the wet/dry feeders so the drinker would be lodged open. The values for F1 WD with wet/dry...
feeders in Fig. 3.5 have considered extenuating circumstances, including accounting for water leakage in the trial and correcting data to remove water leakage.

3.7.5 Feed water

The feed water input into the rooms is presented in Fig. 3.6. Since the feed water was a percentage of the FD, there was also no statistical difference in feed water between feeder types (p>0.05). The error bars consider both the feed cart scale (±0.5 kg) and the laboratory scale error (±0.001 kg). The average daily feed water into the room for grower pigs was 0.3 kg·pig⁻¹·day⁻¹ for both feeder types, and for finisher pigs the average daily feed water was 0.5 kg·pig⁻¹·day⁻¹ for both feeder types.

Figure 3.6: Summary of average daily feed water (ADFW) into the rooms for all trials in kg·pig⁻¹·day⁻¹.
3.7.6 Metabolic water

Calculations to determine metabolic water produced were done using methods presented by both Shaw (2002) and Yang et al. (1984). Less than a 6% difference was seen between the two methods, so it was concluded that the method presented by Shaw (2002) was suitable for this experiment. Figure 3.7 presents the results using methods by Shaw (2002). For a grower pig on both dry and wet/dry feeders, the average metabolic water produced was 0.9 kg·pig\(^{-1}\)·day\(^{-1}\). For a finisher pig, the average metabolic water produced was 1.5 and 1.3 kg·pig\(^{-1}\)·day\(^{-1}\) for dry and wet/dry feeders, respectively. As seen in Fig. 3.7, there were no significant differences between feeder types for water produced through metabolic reactions (p>0.05). For a growing pig, Patience and Thacker (1989) predicted 0.9 kg·pig\(^{-1}\)·day\(^{-1}\) of water produced through metabolic reactions, which is comparable to what was measured for this experiment. The error term includes error from the feed cart measurements, which was the accuracy of the scale (±0.5 kg), and the error of the feed moisture content analysis, which was the accuracy of the laboratory scale (±0.001 kg).
Figure 3.7: Summary of average water produced from metabolic reactions (Met W) for all trials on dry feeders in kg· pig⁻¹ · day⁻¹.

3.7.7 Manure production

As with the WD, the manure water (MW) production between the two feeder types was not significantly different for the grower phase, but was significantly different for the finisher phase. As seen in Fig. 3.8, for the grower pigs the average MW produced was 5.5 and 4.4 kg· pig⁻¹ · day⁻¹, on dry and wet/dry feeders, respectively. The finisher pigs produced an average of 7.7 and 5.4 kg· pig⁻¹ · day⁻¹ of MW on the dry and wet/dry feeders, respectively, which was a 29% reduction in manure production. For the entire grower-finisher cycle, there was a 25% reduction of MW production, or 1.7 kg· pig⁻¹ · day⁻¹. ASAE (2002b) predicts that 84 kg of manure with 11 kg of
solids is produced per 1000 kg live animal mass per day. For the grower phase, taking the average mass of the grower pig, this would be 2.8 kg·pig⁻¹·day⁻¹. For the average mass of the finisher pigs, this would be 6.3 kg·pig⁻¹·day⁻¹. The value measured for the grower phase was higher than that predicted by ASAE (2002b), but the value was closer for pigs in the finisher phase. Since the data presented by ASAE (2002b) are combined from a wide base of published and unpublished information on livestock manure production, differences in measured and predicted values may be expected. The differences seen between measured and predicted manure production may be due to differences in animal diet, age, productivity, spillage and barn management procedures. As with their WD, van’t Klooster and Greutink (1993) do not present average values of MW for their study, but graphs were presented which included the MW over the course of the study. These values were extracted and averaged, and the average MW for the grower-finisher cycle was 3.6 kg·pig⁻¹·day⁻¹, which was also lower than what was measured for this experiment. Again, different conditions may affect the WD, which also affects the MW.
Figure 3.8: Summary of average daily manure water (MW) for all trials on wet/dry feeders in kg · pig⁻¹ · day⁻¹.

Since finisher pigs tend to eat and drink more than grower pigs, the MW production was higher for finisher pigs on both feeder types than the grower pigs, as seen in Fig. 3.8. However, as with the WD, because the pig performance was not statistically different, we can assume that the difference in MW volume is likely due to an increase in water spillage for the pigs on the dry feeders as compared to the pigs on the wet/dry feeders.

The error bars on this graph include the error from the calibration of the manure pits, which included both the error of the depth measurements, which was ±0.4 mm, and the error of the measurements of water volume, which was ±0.5 L; the error from the
manure depth measurements throughout the trials, which was ±0.4 mm; and the moisture content analysis error, which was assumed to be 5% based on scale error.

A low manure production value for both rooms was seen in G3 as compared to G1 and G2. During this trial problems were encountered with the manure pit plugs popping out and leaking, which may have given us faulty data for this trial. This data was analysed closely to extract the measurements where no plug popping problems occurred. There was no evidence in G3 that the final dataset had any leakage in the manure pits, which is why the data was included in the water balance.

The moisture content of the manure varied from 79 to 93%, and the average manure moisture content was 88% for the dry feeders and 87% for the wet/dry feeders. A calculation was done to determine the expected moisture content of the manure produced from both dry and wet/dry feeding systems. Assuming the volume of manure from the dry feeders is 40% higher than for the wet/dry feeders due to spillage, and assuming the pigs on the wet/dry feeders consume 5% more feed than the pigs on the dry feeders, meaning there would be 5% more dry matter in the wet/dry pit, we would expect to see less than a 4% difference in moisture content between the two manure pits. Based on the calculations, for the manure produced using dry feeders, we would expect to see 92.9% water content, and for the manure produced with the wet/dry feeders we would expect to see 89.5% water content.

From the manure sample analysis, the moisture content of the samples from the two manure pits were very similar, and within the range we would expect to see based on
the above calculation. However, from handling the manure, the manure from the
wet/dry feeders did appear to be denser than the manure from the dry feeders. Since
there was not as much water in the manure pits with the wet/dry feeders as with the
dry feeder manure pits, the manure did not flow as smoothly in the wet/dry feeder
pits. As well, if the manure pits were not cleaned regularly, we may expect to see a
build up of manure solids in the pits. If wet/dry feeders are to be used in a
commercial operation, further research should be done to ensure the manure handling
from the wet/dry feeders is handled in the best way possible.

3.7.8 Water deposition in pigs

Figure 3.9 summarises the water retained by the pigs for each trial. The water
retained in the pigs is the difference between the water content of the pigs at the end
of the trial and the water content of the pig at the beginning of the trial. For grower
pigs, the water was 0.4 kg·pig⁻¹·day⁻¹ for both dry and wet/dry feeders, and for
finisher pigs the water retained was 0.7 kg·pig⁻¹·day⁻¹ for both dry and wet/dry
feeders. There was no significant difference in water content of the pigs for either
grower or finisher pigs based on feeder type. The amount of water retained for pig
growth measured for this experiment was consistent with the results from Patience
and Thacker (1989). The error for the water content of the pigs include error for the
ultrasound measurements, which was ±1.0 mm error for fat and muscle thickness,
and ±0.5 kg for the weight measurements.
1.0

Figure 3.9: Summary of average daily water retained by the pigs (W pigs) for all trials in kg·pig⁻¹·day⁻¹.

3.7.9 Water removed by ventilation

Figure 3.10 summarises the water removed from the room by the ventilation. For grower pigs the moisture removed by ventilation was 2.6 and 2.7 kg·pig⁻¹·day⁻¹, and for finisher pigs the moisture removed by ventilation was 4.4 and 3.7 kg·pig⁻¹·day⁻¹ for dry and wet/dry feeders, respectively. Based on prediction equations provided by CIGR (1984), the amount of water removed by ventilation for the grower phase was 2.4 kg·pig⁻¹·day⁻¹ and for the finisher phase the water removed by ventilation was 3.8 kg·pig⁻¹·day⁻¹. This is comparable with the values that were measured in the experiment. As well, van ’t Klooster and Greuntink (1993) found the moisture removal by ventilation in a pig building with deep litter for grower/finisher swine was between 3.7 and 4.7 kg of water per pig per day. These values were expected to
be higher than what was measured for this experiment because there would be more moisture released to the air by MP during composting of the litter. The difference in water removed by ventilation was not significantly different between feeder types for either the grower or finisher phases.

Figure 3.10: Summary of average daily water removed by ventilation (W vent) for all trials in kg·pig⁻¹·day⁻¹.

F2 appears to have a higher amount of water ventilated than was expected, and this is probably due to underestimating the outside relative humidity with the data obtained from the nearby weather station. However, the data was studied closely and the best correlation was used to estimate the outside relative humidity. The error bars for this graph include the accuracy of the thermocouples (±0.5°C), the accuracy of the
relative humidity sensors (2%), and the accuracy of the fans, which was determined using the error between the actual and calculated fan performance values using the developed fan calibration curves. These error values were 15, 8 and 2% for stage 1, 2 and 3 fans respectively.

3.7.10 Water balance of grower-finisher rooms

The water balance of the rooms are summarised in Figs. 3.11 and 3.12 for the grower and finisher pigs, respectively. As mentioned in the preceding sections, there were no significant differences in any source or sink of the water balance for the grower phase (p>0.05), but there were significant differences in WD and MW production (p<0.05) in the finisher phase.
Figure 3.11: Summary of the average daily water balance for all trials with grower pigs (Water disappearance (WD), feed water (FW), metabolic water (Met W), manure water (MW), pig water content (PW), and ventilated water (W vent)).
Figure 3.12: Summary of the average daily water balance for all trials with finisher pigs (Water disappearance (WD), feed water (FW), metabolic water (Met W), manure water (MW), pig water content (PW), and ventilated water (W vent)).

The error terms in Figs. 3.11 and 3.12 are positive, indicating that the sources for the water balance were underestimated, or that the sinks were overestimated. The error bars for each term in the water balance presented in Figs. 3.11 and 3.12 were calculated based on error values associated with each measurement and considered the maximum error possible with each term. The error bars for the feed water and metabolic water are so small that they are not easily visible on Figs. 3.11 and 3.12.
The error term presented in the water balance is the difference between the measured sources and sinks of water. When the total possible error was compared with the actual error term in the water balance, it was found that the measured error term was less than the maximum error for the whole water balance. For example, in Fig. 3.11 the error term for the water inputs on dry feeders is 1.3 kg·pig⁻¹·day⁻¹ and the sum of the error bars is 1.9 kg·pig⁻¹·day⁻¹. As a result, it may be concluded that the water balance that was measured accounts for all the sources and sinks of water in the grower-finisher room for both the grower and finisher trials.

The major source of water in the grower phase for both feeder types is at the drinker, which contributes up to 72% of the water source, and the major sink of water is in the manure, which accounts for up to 64% of the water. Ventilated water also contributes up to 36% of the water leaving the room. The moisture in the feed contributes less than 4% of the water source, and the water produced through metabolic reactions is up to 13% of the total water source. The water retained in the pig is less than 6% of the water sink. The error term accounts for 16% of the sources of water. Similarly, the same significant sources and sinks are seen for the finisher phase with both feeder types, with water at the drinker contributing up to 73% of the source, metabolic water contributing up to 16% and feed moisture contributing 4% of the water source. For the water sinks of a finisher room, the manure contributes 60%, the water retained in the pig is at 8%, and water leaving through ventilation is 38% of the total water sink. The error term accounts for 17% of the sources of water.
Further research should be done on the significant sources and sinks of water, which is at the drinker level and in the manure, to help minimise water usage. The water balance also clearly shows that use of wet/dry feeders as compared to dry feeders will result in a water savings at the drinker level and in the manure pits, due to a reduction of spillage with the wet/dry feeders. To minimize water wastage for swine operations, different drinkers and feeders may be selected that reduce water at the drinkers.

There are several key points that are important when considering water conservation in swine barns. Drinker type has an impact on WD, as different drinkers have an impact on the amount of spillage that may occur. Cleanliness of the drinkers is also important, as pigs prefer to drink from clean water sources. Maintenance is relevant as different drinkers require different levels of maintenance. As an example, drinkers in wet/dry feeders require daily inspections to ensure feed isn't caking in the trough and lodging the drinker open. Conversely, nipple drinkers need to be adjusted regularly to ensure the height of the drinker is at an optimal level in relation to the pig size to discourage spillage. The drinker design is important to ensure the pig uses the drinker in the manner intended to minimise spillage. The flow rate of the drinkers is significant since higher flow rates have been associated with increased spillage, especially if the flow rate is higher than the rate at which the pig can drink. Location and number of both the drinkers and the feeders within the pen may influence the WD. Water quality and the temperature of both the room and the water affect the WD. Feed composition may increase water consumption beyond the needs.
of the pig if excess nutrients and minerals are in the food that affects the water intake of the pig. Availability of food is relevant, if the pig does not eat as much food as it would like, they generally increase their water consumption for gut fill.

When considering water in the manure different options may be explored, including designing devices to direct spillage from the drinkers away from the manure pit. This water may be recycled within the barn for power washing, or the spilled water may be treated and fed back into the water supply for the pigs. A system may be set up onsite to extract water from the slurry, which also may be treated and fed back into the barn for power washing or for pig consumption.

A large portion of the water input into a grower-finisher room was the moisture that was added to the air by evaporation within the pigs and from wet surfaces. Technologies may be studied to try and extract this moisture from the air at the fan level and possibly recycled within the barn. Condensation may be an option utilised to capture this moisture.

3.8 Summary

ADFI, FC and ADG were not significantly different (p>0.05) for pigs on dry and wet/dry feeders. However, the ADG was generally higher for the pigs on the wet/dry feeders than the pigs on the dry feeders by up to 7% at the finisher level. This increase is likely due to an increase in feed intake by pigs on the wet/dry feeders,
which could mean a reduction in time for the pigs to reach market weight. These values were comparable with literature values.

At the finisher phase, the use of wet/dry feeders represents savings of WD by up to 34%, and a reduction of manure production by up to 29% as compared to dry feeders. As the drinkers contributed up to 73% of the water source and the manure was up to 65% of the water sink, future research efforts to conserve water in a swine barn should focus on the drinkers, manure and even ventilation as ventilation contributed up to 38% of the sink in the water balance.

Several key points may be considered when trying to minimise water usage in swine barns. Selection and maintenance of drinker and feeders, flow rate, location and number of drinkers and feeders, water quality, water and air temperature, feed composition, availability of both feed and water are all important factors when attempting to minimise water wastage. Spillage from drinkers may be captured and recycled in the barn for power washing or drinking water. The manure may be treated on site to try to extract water and treat and recycle the water within the barn as well. Moisture in the room air may be captured through condensation mechanisms and also utilised within the room.

The use of wet/dry and dry feeders generated manure that had similar moisture contents, which were around 90%, but the manure from the wet/dry feeders appeared to be denser than the manure from the dry feeders. As a result, manure from the
wet/dry feeders is more likely to increase complications in manure handling if the manure pits are not cleaned regularly. Since use of wet/dry feeders means a substantial reduction in WD and manure volume, future research should be done to determine how the manure from wet/dry feeders might be handled in an efficient manner. Scrapers may be used to remove the manure from the pits, or perhaps substances may be added to the slurry to break down the dry matter into a more fluid material so the manure is easier to handle.
4.0 MOISTURE PRODUCTION FROM GROWER-FINISHER PIGS:
FIELD MEASUREMENTS COMPARED WITH THEORETICAL VALUES


4.1 Introduction

Animal MP provides the fundamental information needed to design and operate ventilation systems for livestock production, particularly for moisture control in winter conditions. It is commonly believed that controlling the ventilation rate for MP is enough to ensure the contaminant levels in the room (NH$_3$, CO$_2$) are at acceptable levels. Various organizations have published empirical equations or suggested MP values used in the design of swine housing (ASAE 2002a; ASHRAE 2001; CIGR 1984; 2002). The values used by both ASAE (2002a) and ASHRAE (2001) were established as early as 1959 (Bond et al. 1959). Barn management practices, swine genetics, and ventilation systems have all evolved considerably since then and all these operating parameters may have an effect on swine MP. An
improved knowledge of actual swine MP will allow for a more confident design of
ventilation systems to control moisture levels inside barns.

Moisture is added to the air within a production building or room by evaporation
from the animals and from the floor and other building surfaces (CIGR 1999). In
most livestock animals, including swine, there are few or no sweat glands so the
lungs play an important role in the dissipation of heat. Expired air is saturated with
water and represents a substantial water loss, even for an animal at rest in a cool
environment. These losses are of considerable magnitude and are related to the
environmental temperature and pig size (Maynard and Loosli 1971). Other factors
affecting MP due to evaporation from the room include air velocity (Koerkamp et al.
1999) and floor type (CIGR 1984).

If the MP within the room is known, the optimal minimum ventilation rate (VR) of
the room may be calculated. In 1984 the International Commission of Agricultural
Engineering (CIGR) published equations used to calculate MP for a production room
filled with pigs based on room temperature, pig mass and floor type. These equations
were updated and a fourth draft of the CIGR working report has been put together
(CIGR 2002), which includes revised MP equations. As well, ASAE (2002a) and
ASHRAE (2001) use equations derived by Bond et al. (1959) for their MP
estimations for different pig weights and inside temperatures. Bond et al. (1959)
published MP prediction equations for grower-finisher pigs between 23 and 181 kg at
inside temperatures between 4 and 38°C, based on pig weight and air temperature.
If the current MP by grower-finisher swine is lower than predicted, the room has likely been designed for over-ventilation in the winter because the small fans in the room have been selected based on the predicted maximum MP rate. If the MP was actually lower than predicted, the small fans may actually be too big to efficiently maintain a lower minimum VR to minimize the amount of supplemental heat added to the room. Conversely, if the current MP by grower-finisher swine is actually higher than predicted, the VR to control for a higher minimum MP may mean critical conditions will exist in the winter. If the minimum VR needs to be set at a higher rate, then the heater capacity may not be large enough to compensate for a higher VR in very cold conditions. This may have detrimental effects, particularly in extremely cold conditions with small pigs. If the pigs are outside their thermoneutral zone, energy is diverted from productive purposes to increase heat production (Bruce and Clark, 1979). This energy diversion would adversely affect the growth rate of the pigs.

Additional considerations of excess humidity in the room include fostering of bacterial and microorganism growth and building deterioration (ASAE 2002a). The performance of the pig may also be adversely affected if the RH in the room is above 80% (Massabie et al. 1997). To prevent possible frost build up on air inlets within the room, adequate minimum VR to control for humidity levels are needed. If the VR is inadequate, when the VR changes and the air inlets are to move when frozen, the inlets may become damaged.
With the increase of lean-growth genetics in the swine industry, MP has increased from that presented in the literature. Research has shown that the newer high-lean growth swine has reduced tolerance to heat. Neinaber et al. (1997) examined the effects of heat stress on moderate-growth and high-lean growth swine. This reduced tolerance to heat by the newer genetic lines of grower-finisher swine may mean an increase in MP in these conditions as pigs try to regulate their body temperature.

Harmon et al. (1997) showed that MP in early-weaned pigs of the newer genetic lines was increased 70 to 135% over the current ASAE standards. Brown-Brandl et al. (1998) measured the effect of acute heat stress on MP for finisher high-lean-growth barrows. The authors reported that the design criteria from Bond et al. (1959) underestimate heat production for barrows at thermal neutral conditions (18-24°C) by approximately 26%, likely due to the increase of lean tissue deposition for the modern high-lean genetic strains. Xin et al. (1999) measured the MP of modern isowean pigs (3.5-4.0 kg) and also confirmed that the current MP of the young pigs and their housing system was higher as compared to those used by ASAE (2002a).

Similar MP studies have been done for other animals, including broilers. Xin et al. (2001) found that the latent heat production in modern broiler houses was less than what was found in the literature, likely resulting from use of nipple drinkers as compared to open-surface (trough) waterers, which may have reduced the surface
area of water available for evaporation. The results from this study revealed that modern broilers exhibit higher metabolic rates than seen in the past, presumably resulting from faster growth rate and improved nutrition. Since the studies done to measure MP of swine by Bond et al. (1959) were done using open-faced waterers, it is reasonable to assume that the current MP within grower-finisher rooms will also be different when nipple drinkers are used.

A moisture balance of a pig building using a deep litter manure management system was determined to measure the MP within the room over a four-month period (van’t Klooster and Gruentink 1993). Composting of the litter produces water and heat, and the heat is partially released as latent heat and causes a major part of the moisture in the litter to evaporate. At the house level for grower-finisher pigs the average measured MP was 0.049 and 0.038 kg pig⁻¹ 15 min⁻¹ for high (19.3°C) and low (12.1°C) temperatures, respectively, which the authors reported was higher than traditional pig houses.

In animal houses, diurnal variations of heat production and MP exist due to differences in animal activity throughout the day (Pedersen and Rom 1998). According to Pedersen and Takai (1997), the calculations using CIGR (1984) give reasonable values of MP of swine on a 24-hour basis, but there may be a considerable deviation between calculated and measured indoor climate during each 24-hour cycle. As an example, Xin et al. (1996) found that animal heat production of broilers in indirect calorimeter chambers was about 25% lower when it was dark than
when it was light. In order to predict the diurnal MP of swine, animal activity levels need to be recorded. Pedersen and Rom (1998) developed an activity measuring system based on infrared detectors, and showed that about 65% of the variation in heat production could be explained by variations in animal activity. According to CIGR (2002), worldwide equations are not currently available for adjustment of animal heat production according to diurnal variations. For some well-defined specific housing and management situations, however, information is available based on animal activity recordings. Pedersen and Takai (1997) reported a sinusoidal equation that predicts animal activity based on time of day and provide constants in the equation based on measurements of animal activity in Denmark by Pedersen (1996).

Modeling is a powerful tool to assist in the design of intensive livestock operations. Dynamic models have been developed to simulate the environmental conditions inside a grower-finisher barn (Zhang et al. 1992). A comparison of the measured MP values and the prediction equations will identify if any of the MP predictor equations are suitable for dynamic MP modeling.

Nienaber et al. (1987) provided information to update the design criteria for grower-finisher pigs, but the ASAE standards have not yet been updated. Such studies need to be regularly completed for other livestock animals to determine the need for systematic updating of heat production and MP data for efficient design and operation of livestock ventilation systems.
The objectives of this study were to:

1. To measure MP in a modern swine barn for grower-finisher pigs on dry and wet/dry feeders.

2. To compare MP measurements with selected moisture prediction equations and suggested values in order to either validate the MP predictions and empirical values currently used or to demonstrate the need for revised MP prediction equations by swine.

This experiment was not designed to change the MP prediction equations in any way, but rather only to compare actual measured MP results with predicted values.

4.2 Materials and methods

This experiment was done using data collected from the water balance experiment as detailed in Chapter 3, and the materials and methods for this project are as outlined in section 3.4. To determine mass flows of water removed by ventilation, the psychrometric properties of the inside and outside air were determined using equations given by ASHRAE (2001). The MP was then calculated and averaged over 15-min intervals by solution of the following steady-state equation:

\[ \text{MP} - \frac{VR \cdot (W_e - W_o)}{v} = 0 \]  \hspace{1cm} (4.1)
where:

\[ \text{MP} = \text{moisture production rate, kg/s}, \]
\[ \text{VR} = \text{ventilation rate, m}^3/\text{s}, \]
\[ W_e, W_o = \text{humidity ratio of exhaust and outside air, respectively, kg}_{\text{water}}/\text{kg}_{\text{dry air}}, \]
and
\[ \nu = \text{specific volume of dry air, m}^3/\text{kg}_{\text{dry air}}. \]

Both the 1984 and the 2002 editions of the CIGR handbooks were used to compare the measured MP with predicted MP values for the pigs at the house level. The 2002 edition includes daily feed energy intake, which is not specified in the 1984 edition, and CIGR 1984 considers a floor factor in calculating MP of fattening pigs, which is not included in the 2002 edition. To consider heat production and MP at a temperature other than 20°C, the 2002 edition considers the total heat production for pigs per heat producing unit (hpu). For purposes of this study, for the CIGR 2002 MP values, the number of hpu’s were calculated to determine the MP on a per pig basis. Both ASAE (2002a) and ASHRAE (2001) present tables for the MP of pigs of a certain weight at a certain inside temperature, based on work done by Bond et al. (1959). The original equations were used to determine the predicted MP for the same pig weight and same ambient conditions for which measured values were available. As well, calculations were made for animal activity (Pedersen and Takai 1997) to determine if the animal activity pattern was closely related to the MP patterns measured in this experiment. Three weight ranges were selected for this experiment, 44-46 kg, 73-77 kg and 97-101 kg. The periods for the 44-46 kg weight
range was two days, and for both the 73-77 and 97-101 kg range three days were used.

Equations 4.2 to 4.7 are the equations presented by CIGR (1984) to calculate the MP of fattening pigs.

\[ \Phi_{\text{tot}} = (29 (m + 2)^{0.5} - 40) \cdot F \]  
\[ F = 4 \times 10^{-5} (20-t_i)^3 + 1 \]  
\[ \Phi_s = \Phi_{\text{tot}} [0.8 - 1.85 \times 10^{-7} (t_i + 10)^4] \]  
\[ \Phi_{s \text{ cor}} = k_s \Phi_s \]  
\[ \Phi_l = \Phi_{\text{tot}} - \Phi_{s \text{ cor}} \]  
\[ \text{MP} = \Phi_l \cdot r \]

where:

\( \Phi_{\text{tot}} \) = animal total heat dissipation in the barn (W),
\( m \) = mass of pig (kg),
\( F \) = temperature correction factor,
\( t_i \) = inside ambient temperature (°C),
\( \Phi_s \) = sensible heat production (J/s),
\( \Phi_{s \text{ cor}} \) = sensible heat production corrected for floor type (J/s),
\( k_s \) = correction factor for floor type, 0.91,
\( \Phi_l \) = latent heat production (J/s), and
\( r \) = specific heat of water (2430 J/gH2O).
Equations 4.8 to 4.18 are the equations presented in CIGR (2002) to calculate the MP of fattening pigs.

\[
\begin{align*}
\Phi_{tot} &= \Phi_m + (1-K_Y)(\Phi_d - \Phi_m) \\
\Phi_m &= 5.09 \cdot m^{0.75} \\
K_Y &= 0.47 + 0.003m \\
\Phi_d &= n \cdot \Phi_m \\
\Phi_s &= 0.8\Phi_{tot} - 0.38t^2 \\
\Phi_l &= \Phi_{tot} - \Phi_s \\
\text{MP} &= \frac{\Phi_l}{\eta} \\
\Phi_{tot-hpu} &= 1000 + 12 \cdot (20-t) \\
n_{hpu} &= \Phi_{tot-hpu} / \Phi_{tot} \\
\Phi_{l-pig} &= \Phi_l / n_{hpu} \\
\text{MP} &= \Phi_{l-pig} / \eta
\end{align*}

where:
\[
\begin{align*}
\Phi_m &= \text{heat dissipation due to maintenance (W)}, \\
K_Y &= \text{coefficient of energy at weight gain}, \\
\Phi_d &= \text{daily feed energy intake (W)}, \\
n &= \text{daily feed energy intake in relation to } \Phi_m, \\
\Phi_{tot-hpu} &= \text{animal total heat dissipation per hpu (1000 W in total heat at 20°C) (W)}, \\
n_{hpu} &= \text{number of heat producing units}, \text{and} \\
\Phi_{l-pig} &= \text{latent heat production per pig (W/pig)}. \\
\end{align*}
\]
Equation 4.19 was derived by Bond et al. (1959) for pigs between 23 and 181 kg at inside temperatures between 4 and 38°C:

\[ Y = -0.961 + 0.291x_1 - 0.785x_2 - 0.146x_1^2 - 0.029x_1^2 + 0.1375x_2^2 \] (4.19)

where:
\[ Y = \log \text{ moisture removed (lb/hr)}, \]
\[ 100x_1 = \text{body weight (lb)}, \]
\[ 100x_2 = \text{air temperature (°F)}. \]

A sinusoidal equation (Eq. 4.20) used to predict animal activity of fattening pigs on partly slatted floor was presented in Pedersen and Takai (1997) and CIGR (2002). The empirical values used in Eq. 20 were extracted from Pedersen and Takai (1997).

\[ A_{100} = 100 - 100 \times \frac{b}{a} \cdot \sin\left[\frac{2\cdot \pi}{24} \cdot (h+6-h_{\min})\right] \] (4.20)

where:
\[ A_{100} = \text{relative activity (average = 100)}, \]
\[ \frac{b}{a} = \text{amplitude (43), and} \]
\[ h_{\min} = \text{time of day with minimum activity (hours after midnight, 1.3)}. \]
A test was done after the MP experiment to verify that the air distribution pattern in the room was completely mixed. Thermocouples and relative humidity sensors were placed at five different locations in one of the rooms used for the MP study. These locations include at the fan level; at the far end of the pens away from the fans; near an inlet (outside conditions); in the centre of the room; and the location the temperature and relative humidity were measured for the MP experiment. A 24-hour period was measured and the effects of changes in VR on the temperature and relative humidity at the five different locations were observed simultaneously.

4.3 Results and discussion

The raw data were accumulated in spreadsheets for each trial. Since the swine houses were operated as commercial production facilities instead of direct calorimeters, the data were filtered and edited to obtain reasonable estimates of MP. The filtration and editing process included removing or altering obviously spurious data that resulted from sensor or instrument failure. The data were analyzed manually and values due to instrument error were removed prior to final analysis.

During the last two experimental production cycles, the outside relative humidity data that were recorded at PSCI were much less than expected due to unforeseeable conditions. As a result, these outside relative humidity data were corrected based on data collected by Environment Canada at a weather station near PSCI. The data were then compiled to compare the measured MP results to predictions for pigs with identical weights and inside room temperatures.
4.3.1 Pig performance

Tables 3.3 and 3.4 summarize the starting and ending weights for each trial, as well as the ADG for each trial. For this project only experiments 1 and 2 were used. Gonyou (1996) reported an ADG value of 0.90 kg per day for a complete grower-finisher cycle across all feeders. This compares to the overall average of ADG data measured for this experiment, which was 0.87 kg/d. The pens were of mixed gender, so the weight gain represents the average of barrows and gilts. Since the difference between the pigs on the two feeder types was only about 3%, and the statistical analysis showed no significant differences (p>0.05), we can conclude that the feeder type had no impact on pig performance. We may then assume that any differences seen in the MP between rooms with dry feeders or wet/dry feeders is not due to differences in pig weight or performance.

4.3.2 Air distribution study

As seen in Fig. 4.1, when the VR increased, a corresponding increase in MP was observed. In order to explain this pattern, measurements of the temperature and relative humidity were made at five different locations in one room to determine if the air in the room was completely mixed. The temperature and relative humidity measured in the room over a one-hour time period where the VR increased are presented in Figs. 4.2 and 4.3. The humidity in the room was also calculated for the same time period and is presented in Fig. 4.4.
Figure 4.1: Measured moisture production (MP) vs. calculated moisture production for grower pigs (27-29 kg) on wet/dry feeders in the first experiment in kg 15·min⁻¹·pig⁻¹. The average ambient temperature for this period was 21.3°C. The ventilation rate for the same time period is also presented.
Figure 4.2: Temperature measurements at five locations (1-normal experimental measuring location; 2-air inlet (outside conditions); 3-far side of room opposite fans; 4-centre of room; 5-fan level) and ventilation rate (VR) inside one room over a one-hour period.

The temperatures at the five locations were relatively stable but not the same in the five locations. When the VR increased, the temperature inside the room, especially at the normal experimental measuring location, dropped slightly. This is likely due to the increase of cooler air flowing over the temperature sensor as the normal experimental measuring location was very close to the air inlets. This indicates that the air distribution in the room did not mix rapidly enough to accommodate this
volume of cooler air entering the room. However, the temperature appeared to stabilize and return to normal after a few minutes.

Figure 4.3: Relative humidity (RH) measurements at five locations (1-normal experimental measuring location; 2-air inlet (outside conditions); 3-far side of room opposite fans; 4-centre of room; 5-fan level) and ventilation rate (VR) inside one room over a one-hour period.

In Fig. 4.3 the inside relative humidity appears to generally follow the same pattern as the outside relative humidity. This is to be expected, as when the outside relative humidity increases or decreases when the inside temperature remains constant, the
humidity entering the room also increases or decreases, affecting the total humidity in the room.

Figure 4.4: Humidity ratio measurements at five locations (1-normal experimental measuring location; 2-air inlet (outside conditions); 3-far side of room opposite fans; 4-centre of room; 5-fan level) and ventilation rate (VR) inside one room over a one-hour period.

The combined effects of temperature and relative humidity are seen in Fig. 4.4. The inside humidity at all locations appear to follow the same pattern as the outside humidity, but the inside humidity is higher than the outside humidity, which is to be
expected as moisture is being added to the inside air by evaporation from the pigs and building surfaces.

The instrument response time for both the temperature and relative humidity sensors appear to be rapid enough to respond to the changes in the air inside the room. Based on the results from the air distribution study, it is unclear why the MP increases when the VR increases. It is likely that the calculations for MP are not considering the additional moisture entering the room when the VR increases, and the airflow into the room increases. The outside relative humidity and temperature sensors were not checked for the air distribution study, and were found to be erroneous at the end of the experiment, and may likely be where the fault lies for the response of MP to VR. The outside relative humidity values recorded for the study are likely too low, not allowing final calculations for MP inside the room to account for the additional moisture entering the room when the VR increases.

From Fig. 4.1, if the periods where the VR increases are neglected, then the MP within the room appears to be constant and match closely with the CIGR (1984) prediction equations. For purposes of determining the moisture content of the air, only the periods where the ventilation rate was at a minimum were considered.
4.3.3 Data compilation

Due to instrument failure at various times throughout each experiment, it was difficult to select any weight range over a three-day period where complete data was available for each weight range from each trial. As well, due to the results from the air distribution study, the periods were selected, where possible, when the VR was constant over the three days. Weight ranges from 43-45 kg (two days), 73-77 kg (three days), and 97-101 kg (three days) were selected to compare the average measured values from both experiments with predicted values. The same time periods were also compared for similar weight conditions. The MP for the two grower trials were averaged and the MP was also averaged for the two finisher trials, and are presented for both the 43-45 kg and the 97-101 kg weight range. However, for the 73-77 kg weight range only data from the first experiment was used. In Trial 2 the relative humidity measurements for the room with the dry feeders were not available due to instrument error. Comparisons of the relative humidity levels inside the two rooms for the other three trials were made and were nearly identical. As a result, the data from the room with the wet/dry feeders was substituted in the data for the room with the dry feeders, and the MP of the room was then calculated.

4.4 Comparisons with literature data

Since the data was collected and averaged over a 15-min period, the pig weight was calculated and averaged over a 15-min period based on its starting weight, ADG and
elapsed time from the starting weight. The calculated pig weight, temperature recorded and heat from feed intake were then used to calculate the MP expected by the pigs using equations from Bond et al. (1959), CIGR (1984), and CIGR (2002) equations. A value of 0.91 for the $k_s$ factor and corresponding to partially slatted floors was considered for the CIGR (1984) equations.

Figures 4.5 to 4.7 show the measured MP and the predicted MP from CIGR (1984, 2002) and Bond et al. (1959) over 15-min intervals for body mass classes of 43-45, 73-76, and 97-101 kg, respectively, all on dry feeders in the first experiment. As seen on Figs. 4.5 to 4.7, the prediction equations all underestimate the average measured MP for the three weight ranges. As suggested by Brown-Brandl et al. (1998), this may be due to the increase of lean tissue deposition for the modern high-lean genetic strains. For the 43-45 kg weight range the CIGR (2002) equations predict a higher MP than the CIGR (1984) equations, but for the 97-101 kg weight range, the CIGR (1984) equations predict a higher MP than the CIGR (2002) equations. At the 73-77 kg weight range both CIGR (1984) and CIGR (2002) were very similar.

In addition, Figs. 4.5 to 4.7 show diurnal patterns of MP with peak activities in the afternoon that the prediction equations do not reflect. At periods of maximum measured MP the CIGR (1984) prediction equations underestimate actual MP by as much as 56%. As a result, the VR is actually too low to maintain desired humidity levels at high MP peaks during the day in cold conditions. A possible solution to this
problem may be to control the VR based on humidity levels inside the rooms in cold conditions, not based on temperature. If this approach is not suitable, the maximum daily MP levels should be used when designing room ventilation systems, and not the average daily MP.

Figure 4.5: Measured moisture production (MP) and calculated moisture production for grower pigs (43-45 kg) on dry feeders in the second experiment in g·15 min\(^{-1}\)·kg\(^{-1}\) from March 7-9, 2001. The average ambient temperature for this period was 15.5°C.
Figure 4.6: Measured moisture production (MP) and calculated moisture production for finisher pigs (73-76 kg) on dry feeders in the first experiment in g· 15 min⁻¹· kg⁻¹ from December 16-19, 2000. The average ambient temperature for this period was 19.3°C.
Figure 4.7: Measured moisture production (MP) and calculated moisture production for finisher pigs (97-101 kg) on dry feeders over three and a half days in the first experiment in g·15 min⁻¹·kg⁻¹ from January 11-14, 2001. The average ambient temperature for this period was 18.2°C.

Figure 4.8 presents a summary of the average measured MP and the average predicted MP for the three different selected weight ranges of pigs on dry feeders in kg 15 min⁻¹ pig⁻¹. The measured MP was consistently higher than those yielded by all prediction equations used in this study. The measured MP was, on average, higher than the CIGR (1984) predictions by 8%; the CIGR (2002) predictions by 13%; and the Bond et al. (1959) predictions by 31% for pigs on both feeder types in both experiments. This is in agreement with the results from Brown-Brandl et al.
(1998), in which they reported that Bond et al. (1959) underestimated heat production, which is related to MP, for barrows by 26%. In addition, as the pig weight increases the percent difference between the measured and predicted values also increases.

Figure 4.8: Comparison of average moisture production (MP) in kg·15 min⁻¹·pig⁻¹ values for pigs on dry feeders: current, CIGR (1984), CIGR (2002), and Bond et al. (1959) for three different weight ranges.

Since nipple drinkers were used for this study, as in Xin et al. (2001) the MP was expected to be less than what was measured for Bond et al. (1959) where open-faced waterers were used, due to a decrease in surface area available for evaporation from the drinkers. However, the MP in the current study was higher than what Bond et al.
(1959) found, likely due to an increase of lean tissue deposition for modern high-lean genetic strains as described by Brown-Brandl et al. (1998).

Figure 4.9 is a sample of the error values associated with the MP measurements. For this time period the average error was 13%, which encompasses the calculated MP.

Figure 4.9: Error values of measured moisture production (MP) and the CIGR (1984) calculated moisture production for finisher pigs (97 kg) on dry feeders in the first experiment.

Some authors suggest presenting MP results using metabolic body weight (BW), as compared to total BW (NRC 1998; Heusner 1982). NRC (1998) suggests using a
metabolic BW of BW\(^{0.75}\). Other exponents have been suggested as more appropriate, including 0.67 (Heusner 1982). Figures 4.10 and 4.11 show the difference in results when using metabolic BW as compared to total BW. Intuition would suggest that larger pigs would produce more moisture than smaller pigs, which is the case as seen in Fig. 4.8. However, smaller pigs actually produce more moisture on a per kg basis, as seen in Fig. 4.10. This may be because there is likely more lung area per kg of total BW for smaller pigs than for larger pigs; therefore less moisture is being produced per kg of body weight. The MP per kg of metabolic BW in Fig. 4.11 shows that, when presented in terms of metabolic BW, the MP is very comparable between different body weights. This is useful since the metabolic BW considers only the metabolically active tissue in the body, making comparisons of MP by different pig weights possible.

The data presented in Figs. 4.10 and 4.11 includes water from evaporation from building and manure surfaces, not just water evaporated by the pig. As a result, the majority of the results are presented in terms of kg of total BW and not metabolic BW, which is generally more appropriate when considering MP only at the pig level and not at the room level. In all cases, the MP prediction equations underestimate the actual MP measured in the room by the same proportions whether the results are presented per kg of total BW, per kg of metabolic BW or per pig.
Figure 4.10: Comparison of average moisture production (MP) in g·15 min⁻¹·kg⁻¹ values for pigs on dry feeders: current, CIGR (1984), CIGR (2002), and Bond et al. (1959) for three different weight ranges.
Figure 4.11: Comparison of average moisture production (MP) in g·15 min⁻¹·kg⁻¹ (Body Weight^0.67)⁻¹ values for pigs on dry feeders: current, CIGR (1984), CIGR (2002), and Bond et al. (1959) for three different weight ranges.

4.4.1 ks factor (CIGR 1984)

As presented in Figs. 4.12 and 4.13, when the ks factor was dropped from 0.91 to 0.88 for 43-45 kg pigs on the dry feeders in the 1984 CIGR MP equation, the predicted MP did not more closely match the measured MP average. However, for the 73-77 kg pigs the predicted MP did match more closely to the measured MP when the ks factor was dropped from 0.91 to 0.85. This inconsistency may suggest different ks factors are appropriate for different weight ranges of fattening pigs.
However, the difference between the average measured MP of pigs on the dry feeders and the calculated MP using the $k_s$ factor of 0.91 only had about a 5% difference in the first experiment. Changing the $k_s$ factor does not help predict the diurnal patterns of MP, but may be appropriate when considering MP averages in livestock building design.

![Graph showing the effects of changing the $k_s$ factor in the CIGR (1984) moisture production (MP) prediction equation for 43-45 kg pigs on dry feeders over two days in the first experiment as compared to the measured moisture production.](image)

**Figure 4.12:** Effects of changing the $k_s$ factor in the CIGR (1984) moisture production (MP) prediction equation for 43-45 kg pigs on dry feeders over two days in the first experiment as compared to the measured moisture production.
Figure 4.13: Effects of changing the $k_s$ factor in the CIGR (1984) moisture production (MP) prediction equation for 73-77 kg pigs on dry feeders over two days in the first experiment as compared to the measured moisture production.

Table 4.1 summarizes the changes in the results for the data from the CIGR equations when the $k_s$ factor is at 0.91, 0.88 and 0.85 for pigs at 43-45, 74-77 and 97-101 kg for the pigs on dry and wet/dry feeders in the first experiment only. According to this experiment, to predict MP the $k_s$ of 0.91 for grower-finisher swine on both dry and wet/dry feeders appears to be appropriate, with a 5% difference between the average measured MP and the calculated MP using CIGR (1984) equations for the first experiment. When the $k_s$ factor was decreased from 0.91 to 0.88 in the CIGR (1984) predictor equations, the MP was generally overestimated, but for the 73-77 kg weight range decreasing the $k_s$ factor did improve the accuracy...
of the average predicted MP. Since this experiment was not designed to test the \( k_s \) factor, it is suggested that future research be done to evaluate the suitability of the current \( k_s \) factors used in the CIGR (1984) equations to improve the 24-hour average MP of grower-finisher pigs.

Table 4.1: Summary of averaged measured and calculated moisture production values in kg· 15 min\(^{-1}\)· pig\(^{-1}\) using CIGR (1984) equations and \( k_s \) factors of 0.91, 0.88 and 0.85 for pigs in the first experiment on both dry and wet/dry feeders.

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Weight (kg)</th>
<th>Average MP (kg· 15 min(^{-1})· pig(^{-1}))</th>
<th>( k_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measured</td>
<td>0.91</td>
</tr>
<tr>
<td>Dry</td>
<td>43-45</td>
<td>0.029</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>73-77</td>
<td>0.039</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>97-101</td>
<td>0.039</td>
<td>0.041</td>
</tr>
<tr>
<td>Wet/Dry</td>
<td>43-45</td>
<td>0.026</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>73-77</td>
<td>0.042</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>97-101</td>
<td>0.042</td>
<td>0.040</td>
</tr>
</tbody>
</table>

4.4.2 Diurnal variation

From the measured data we can see that a diurnal pattern exists that the CIGR (1984, 2002) and Bond et al. (1959) equations are unable to predict (Figs. 4.5 to 4.7). Equation 38 was used to compare the predicted animal activity with the MP diurnal patterns. Graphs were made to compare the results, and the y-axis was set so the average value for both the MP and animal activity for the time period presented was
in the middle, so the amplitudes of the two graphs could be compared. As seen on Figs. 4.14 and 4.15, for pigs on dry feeders the animal activity pattern matched closely with the measured MP values, particularly for the pigs in the 97-101 kg range. For the smaller pigs, a closer examination of the constants used in this sinusoidal equation, including amplitude and average activity over 24 hours, may reveal values that are more appropriate to predict the pattern of animal activity for pigs used in this experiment. Use of this animal activity equation may be suitable for modeling the dynamic patterns of MP as compared to using equations from CIGR (1984, 2002) and Bond et al. (1959), which are more suitable for design purposes rather than dynamic modeling.
Figure 4.14: Comparison of measured moisture production (MP) with animal activity over three days using equations from Pedersen and Takai (1997) for 43-45 kg pigs on dry feeders in the first experiment.
Figure 4.15: Comparison of measured moisture production (MP) with animal activity over three days using equations from Pedersen and Takai (1997) for 97-101 kg pigs on dry feeders in the first experiment.

4.5 Effects of dry and wet/dry feeders on moisture production

A summary of the average MP for the three weight ranges for pigs on dry and wet/dry feeders is presented in Fig. 4.16. From this figure it is apparent that feeder type does not have an effect on swine MP rates within the rooms. Since the drinkers with the dry feeders had more spillage than the drinkers with the wet/dry feeders, it was initially expected that the MP rate within the room with the dry feeders would be higher because of an increase in evaporation of the spilled water from the floor.
However, the MP in both rooms were very similar, and one room did not consistently have a higher MP than the other, likely due to the drinker in the dry feeder room being located over the slats. These slats were wet for both rooms due to pig urination and faecal deposition on the slats, and the addition of spilled water may not have increased the surface area available for evaporation. Another factor that may impact on the results in Fig. 4.16 is the number of days available for each data compilation. Additional measurements may reveal different proportions of MP based on feeder type.

![Graph showing moisture production (MP) for different pig weights and feeder types.]

Figure 4.16: Summary of average moisture production (MP) for pigs on experiments one and two using dry and wet/dry feeders for 43-45, 73-76, and 97-101 kg pigs.
4.6 Conclusions

The MP of two grower-finisher rooms were measured over two complete cycles, with one room using dry feeders and the other room using wet/dry feeders. The measured MP values were compared against three separate MP prediction equations to determine the validity of the measured values. If differences exist between actual and predicted MP in a grower-finisher building, concerns may arise with the ventilation and heating system design in current swine buildings. This in turn may affect the condition of the building shell and the growth performance of the pigs.

An air distribution study revealed that the temperature and relative humidity in the room was not identical across the airspace of the two rooms used for the MP study. As well, the instrument response time was not quick enough to account for moisture changes in the room due to changes in VR. Based on these results, the MP analysis periods were selected to correspond to the periods when the VR was stable.

The pig performances indicate that there were no significant differences (p>0.05) in the ADG of pigs on dry and wet/dry feeders, so differences seen in MP between the two rooms used for this study is likely not due to differences in pig performance. CIGR (1984, 2002) and Bond et al. (1959) all underestimate the average MP of grower-finisher swine. CIGR (1984) appears to have the closest match to the measured values, but was on average 8% less than the measured MP for pigs for all
body weights on both experiments. CIGR (2002) and Bond et al. (1959) underestimate the average MP by 13 and 31% for all experiments. These average results are averaged over two and three-day periods. The error terms for the MP encompassed the CIGR (1984) average MP values, but if the MP is considered over 15-min time periods, the CIGR (1984) prediction equations underestimate the measured MP by as much as 56% in peak MP periods, which is not accounted for by error terms. If the heater capacity is insufficient to compensate for an increase in ventilation to control for additional moisture, the pigs may reach temperatures lower than their thermoneutral zone and their growth performance may suffer. When designing ventilation systems the maximum MP should be considered at the peak daily MP to ensure adequate ventilation and heating is available. Another option may be to ventilate based on humidity levels inside the rooms in cold conditions, where the heater also needs to be properly sized.

The $k_s$ factor in the CIGR (1984) equation was decreased from 0.91 to 0.85. The average calculated MP did not reflect the averaged measured values for the grower-finisher swine for the 43-45 kg weight range more closely, but did for the 73-77 kg weight range. This indicates that different $k_s$ factors may be appropriate for different weight ranges. In addition, changing the $k_s$ factor did not reflect the diurnal pattern of MP. Future work could re-examine the appropriate $k_s$ factors that could be used when designing ventilation systems in modern swine facilities.
CIGR (1984) may be suitable to predict average values of MP for design purposes, but should not be used for dynamic modeling. Equations predicting animal activity developed by Pedersen and Rom (1998) appeared to predict the diurnal patterns of MP for the swine studied in this experiment, particularly with 97-101 kg pigs. Further investigation of these equations may lead to appropriate equations that could predict the diurnal MP of swine at different weights.

The use of dry or wet/dry feeders did not affect MP. The only difference that was observed between the two feeder types was a reduction in spillage when wet/dry feeders were used, which may decrease the amount of water available for evaporation in the room. As the slats in both rooms were already wet from dunging, the surface area available for evaporation may not have been different between the two rooms since the drinkers with the dry feeders were located over the slats.

Knowledge of the MP within grower-finisher rooms is important to ensure adequate ventilation and heating is available within the room to maintain proper moisture and temperature levels. Maintaining the proper moisture levels in the room, particularly in cold climates, helps to ensure the long-term life of the building shell and prevents frost and condensation within the room. The pig performance is also best when humidity levels are maintained below 80%. Subsequently, maintaining the proper temperature setpoint in the room helps to ensure optimal pig performance. To ensure that proper ventilation design of intensive swine operations continues, the MP
equations should be regularly validated as pig genetics and barn management schemes continue to evolve.
5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Knowing the significant sources and sinks of water in a grower-finisher room will help to efficiently focus future water conservation research on key areas. In addition, the selection of feeder type may have a large impact on the volume of water disappearance and slurry production within the barn.

The water balance of two grower-finisher rooms were measured over six trials where one room was provided with dry feeders and nipple drinkers, and the second room was equipped with wet/dry feeders. The ADG was generally higher for the pigs on the wet/dry feeders than the pigs on the dry feeders by up to 7% at the finisher level. This increase is likely due to an increase in feed intake by pigs on the wet/dry feeders, which could mean a reduction in time for the pigs to reach market weight.

Many factors are involved when considering water conservation in swine barns. Based on this study, the significant source of water in a grower-finisher room is at the drinker, which contributed 73% of the water source, and the significant sink is in the manure pit, which was up to 65% of the water sink. Future research efforts to
conserve water in a swine barn should focus on the drinkers, manure and ventilation as ventilation contributed up to 38% of the sink in the water balance.

An effective method to reduce water consumption and manure production is to replace dry feeders and nipple drinkers with wet/dry feeders. Wet/dry feeders used 34% less water at the drinker, and manure production was reduced by up to 29% as compared to dry feeders and nipple drinkers. The use of wet/dry and dry feeders generated manure that had similar moisture contents, at around 90%, but the manure from the wet/dry feeders appeared to be denser than the manure from the dry feeders. As a result, manure from the wet/dry feeders is more likely to increase complications in manure handling if the manure pits are not cleaned regularly. Since use of wet/dry feeders results in a substantial reduction in water disappearance and manure volume, future research should be done to determine how the manure from wet/dry feeders might be handled in an efficient manner.

If the MP equations that are currently used underestimate actual MP, then concerns may arise with the ventilation and heating system already in place within the barn, particularly in cold climates. Validation and updating of these equations should be made to ensure design of future barns considers the proper MP rates so optimal moisture and temperature levels are maintained. Data from the water balance study was used to compare the measured MP of the room with three different MP equations for four grower-finisher trials with two trials using dry feeders and the other trial using wet/dry feeders.
CIGR (1984, 2002) and Bond et al. (1959) all underestimate the average MP of grower-finisher swine. However, when the error value for the MP was considered, CIGR (1984) did predict the average MP. But more importantly, when the MP was averaged over a few days, the peak MP periods within the room were neglected. This may have significant effects, including frost build-up on air inlets which may cause damage to the inlets when the ventilation changes. Consideration of peak MP within the rooms should be made when designing ventilation and heating systems. Additionally, in the future control of the ventilation could be based on humidity levels within the room in cold conditions to ensure proper maintenance of the room moisture levels.

CIGR (1984) may be suitable to predict average values of MP for design purposes, but should not be used for dynamic modeling. Equations predicting animal activity provided by Pedersen and Rom (1998) appeared to predict the diurnal patterns of MP for the rooms studied in this experiment. Further investigation of these equations may lead to appropriate equations that could predict the diurnal MP of swine at different weights.

The use of dry or wet/dry feeders did not affect MP rates. The only difference observed between the two feeder types was a reduction in spillage with wet/dry feeders, which may decrease the amount of water available for evaporation in the room. As the slats in both rooms were already wet from dunging, the surface area
available for evaporation may not have been different between the two rooms since the drinkers with the dry feeders were located over the slats.

This experiment was not designed to try to adjust the MP equations used in this study in any way. Consequently these values should not be adapted to any new equations. Rather, a thorough MP study should be done over a complete grower-finisher cycle to try to adapt new MP equations that reflect the current MP activity of swine.
REFERENCES


