Energy requirement for maintenance in growing pigs

H. Everts

Department of Nutrition
Faculty of veterinary medicine
Utrecht University
The Netherlands

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WUR Livestock Research, Dept. Animal Nutrition
P.O. Box 338
6700 AH Wageningen
The Netherlands

Preface

This documentation report is the result of a desk study performed by Henk Everts of the department of Nutrition, Faculty of veterinary medicine of Utrecht University, The Netherlands.
This desk study was done with the aim to evaluate the scientific basis of the net energy formula developed by the group of J. Noblet (INRA) and to judge whether this formula should be used in the update of the Dutch net energy system for growing and fattening pigs.
For further clarification it is referred to (the Preface of) CVB Documentation Report no. 56 (May 2015).

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M.C. Blok
Former manager of the CVB activity of the Product Board Animal Feed /
At the moment advisor of the CVB program, executed by Wageningen Livestock Research, department Animal Nutrition

Content

Abbreviations

BMR	Basal Metabolic Rate
BW	Body Weight
DE	Digestible Energy
$E_{\text{combustible gasses}}$	Energy excreted as combustible gasses
E_{faeces}	Energy excreted with faeces
E_{urine}	Energy excreted with urine
FHP	Fasting Heat Production
HP	Heat Production
Hpac	Heat Production due to physical activity
k_f.	Efficiency of conversion of dietary ME into Energy retained as fat
k_g , k_{diet}	Efficiency of conversion of dietary ME into Retained Energy
k_m	Efficiency of conversion of dietary ME into Net Energy maintenance
$k_m{}^{\#}$	Theoretical Efficiency of conversion of dietary ME into Net Energy maintenance
k_p	Efficiency of conversion of dietary ME into Energy retained as protein
k_r , k_{br}	Efficiency of conversion of body energy into Net Energy maintenance
kJ	kilo Joule
LCT	Lower Critical Temperature
ME	Metabolizable Energy
MEm	Metabolizable Energy required for maintenance
MJ	Mega Joule
NE	Net Energy
NEm	Net Energy for maintenance
$NEm^{\#}$	Theoretical Net Energy for maintenance
NEp	Net Energy for production
RE	Retained Energy
REf	Retained Energy as fat
REp	Retained Energy as protein
TEFlt	Thermogenic Effect for the long term
TEFst	Thermogenic Effect for the short term

1. Energy requirement for maintenance in growing pigs

1.1. Introduction and aim of the report

The Dutch Net Energy formula to predict the NE value of feeds and feed stuffs is derived from a large data set with measured energy retentions and an assumed value for maintenance of 290 kJ NE per BW $^{0.75}$. This value for maintenance is derived from fattening pigs with a high body weight (depositing mainly fat). At the moment, growing pigs have the ability to deposit large amounts of protein in combination with relatively small amounts of fat. A large number of publications indicate that the maintenance requirement of these fast growing pigs needs revision. This report provides some theoretical background concerning the Net Energy requirement for maintenance and proposes a NE value for maintenance for fast growing pigs on the basis of a number of publications from the group of Noblet and co-workers.

This proposed NE value for maintenance is only applicable for growing pigs (up to 140 kg BW) and not for heavier animals (breeding sows and boars).

2. Theoretical background

The application of a Net Energy (NE) system in practice requires a NE value of the diet and a NE requirement of the animal. The NE value of a diet or a feed stuff is estimated with a regression equation using (digestible) nutrients as predictors. The basis for such a regression equation is a set of energy balance trials testing many different diets in growing pigs. Compared to feeding systems based on Digestible Energy (DE) and Metabolizable Energy (ME), a NE system is more complicated. The DE value of a diet can be calculated by subtracting the energy in the faeces from the Gross Energy (GE) in the diet:

[1] $DE = GE - E_{\text{faeces}}$

The ME value of a diet can be calculated by subtracting energy in the faeces, urine and combustible gasses from the GE:

[2] $ME = GE - E_{\text{faeces}} - E_{\text{urine}} - E_{\text{combustible gasses}}$

In contrast to DE and ME, the NE value cannot be measured directly. In an energy balance trial we can measure (indirectly) total heat production (HP) and can calculate retained energy (RE):

[3] $RE = ME - HP$

In a growing animal RE represents Net Energy production (NEp). Thus equation [3] can also be written as:

[4] $NEp = ME - HP$

It is a well known concept that an animal requires a certain amount of energy to stay alive (= maintenance requirement) and that the ingested energy above the maintenance requirement can be used for production. In an adult, non-producing animal NEp is equal to zero and if this animal is fed exactly to its ME requirement, then according to equation [4] ME is equal to HP. The amount of feed required to feed an animal at maintenance level contains ME and represents also a certain amount of NE. So, there must be a Net Energy requirement for maintenance (NEm). If we know the NEm, then we can calculate total NE:

[5] $NE = NEm + NEp$

Now two questions arise: what is NEm and how can it be measured?

2.1. What is NEm?

Theoretically, NEm is the required net energy to stay alive under thermally neutral circumstances without physical activity and without any activity or metabolic process related to feeding. This means that net energy is required for vital functions such as circulation of blood, pulmonary ventilation, keeping the membrane potentials intact, protein turnover, kidney function, activity of brains and compensation for insensible heat loss.
It must be noted that in a more practical setting NEm includes at least some physical activity.

2.2. How is NEm measured?

Unfortunately, it is not possible to measure the value of NEm according to the theoretical description as given at 1.1. Values for NEm originating from literature can differ due to definition and the method of measuring or calculating. Moreover, NEm and other related terms are often mixed and sometimes used in a wrong way. Firstly, some of the most commonly used terms are shortly described.

Basal metabolic rate (BMR) is often measured in adult humans, who are resting in an post-absorptive state under thermally neutral circumstances. BMR is not equal to the minimum level of energy metabolism, because sleep can reduce the BMR by about 10%.

Because voluntary co-operation is missing in animals, it is not possible to measure BMR in animals. In some publications the term "*resting metabolism*" is used, when heat production is measured in animals before the morning feeding. In this situation the post-absorptive state is not always guaranteed and the animal can show more or less physical activity and even in some cases thermally neutral environment was not present.

To be sure that energy expenditure due to eating, digestion and metabolism induced by the intake of the feed doesn't contribute to the total heat production the animal is fasted for a (much) longer period. In such a situation *Fasting Heat Production (FHP)* is measured. With a standardised procedure the measurement of FHP can be reliable and reproducible in animals of a certain genotype and sex. Classically, FHP expressed in kJ per kg metabolic body weight ($kg^{0.75}$) is often equated with NEm.

Also in growing pigs it is common practice to measure FHP and to use this value as NEm. However, there are some points of concern in measuring FHP in growing pigs:

- the animal is fasting and its body weight is gradually decreasing due to loss of gut content and mobilisation of body stores. It is questionable how and when to measure a correct body weight and how it can be translated to the situation of a normally growing animal
- a fasting period of about 72 hours results in a steady state in adult animals, but in young growing animals there is debate about the required period of fasting
- the level of FHP is related to the feeding level before the fasting period. Most reliable results are observed when animals are fed at maintenance during a longer time before the measurement of FHP. This seems an unrealistic situation for growing animals.
- the physical activity of animals during fasting increases compared to animals fed at a high feeding level.

Besides these practical points there is also a theoretical objection against the use of FHP as NEm. During fasting the net energy for maintenance originates from the body stores and the energetic conversion of body energy into NEm (k_r) is less then 1.0. Thus, FHP represents the theoretically NEm ($NEm^{\#}$) plus the heat loss due to conversion of mobilised body energy into $NEm^{\#}$. This leads to the equation:

[6] $NEm^{\#} = FHP * k_r$

To avoid these problems, another possible way to derive a value for NEm is often used. If it is assumed that the relationship between RE and ME is linear, then it possible to calculate the regression line between RE and ME from a set of energy balances trials as:

[7] $RE = ß_1 * ME - C$

In this relationship $ß_1$ equals to the energetic conversion of ME into RE (k_g). At maintenance level RE is zero and thus $C/ ß_1$ equals to MEm. Replacing C by $MEm * ß_1$ leads to:

[8] $RE = k_g * (ME - MEm)$ (only if $ME \geq MEm$)

Thus, the regression model can be used to get an estimate of MEm. The distribution of the observed data can have a large impact on the estimates of k_g and MEm. A high value k_g is always associated with a high estimate for MEm and the other way around.

To make the step to NEm we need to know the energetic efficiency of the conversion of ME into NEm (k_m). An estimate for k_m often calculated as:

[9] $k_m = FHP / MEm$

By doing this, it is assumed that FHP is a good estimate for NEm. As indicated above, the value for k_m is overestimated because FHP includes already the inefficiency associated with the conversion of body energy into $NEm^{\#.}$ From equation [6] it can be seen that FHP equals to $NEm^{\#} / k_r$ and from equation [9] that FHP equals to k_m * MEm. This leads to:

[10] $NEm^{\#} / k_r = k_m * MEm$

The theoretical value for the efficiency of dietary ME used for $NEm^{\#}$ ($k_m^{\#}$) is derived from equation [10]:

[11] $k_m^{\#} = NEm^{\#} / MEm = k_m * k_r$

Depending on the estimated value for k_r the well known gap between k_m and k_g can become much smaller or even disappear. Moreover, if k_r is close to a value of 1, then is seems possible to estimate NEm by extrapolation of the regression between RE and ME to the level at which ME equals to zero. The validity of this method depends on the value of k_r and the distribution of the observed values in the used data set.
It must be concluded that if we want to derive a value for NEm, we need, directly or indirectly, an (estimated or assumed) value for FHP.

2.3. The calculation of the NE value of a diet

As shown in equations [12] and [13] there are theoretically two ways to calculate the NE value of a diet:

[12] $NE = FHP + RE$

where FHP (representing NEm) and RE (representing NEp) both can be measured. It is also possible to estimate NEm from the regression between RE and ME at the level of ME equal to zero. This implies also the assumption that NEm is equal to FHP and that k_r is equal to 1.0.

[13] $NE = MEm*k_m + RE$

where MEm is derived by extrapolating the relation between RE and ME to the level of RE is zero. For k_m a value can be assumed or derived from the ratio FHP: MEm and RE can be measured. It should be kept in mind that the outcome of all these calculations can be influenced by the applied feeding level before measuring FHP or the feeding level during the experiment trying to estimate MEm.
In all cases we assume that FHP equates to NEm. As shown above, all methods to calculated total NE have a theoretical and a practical error.

3. The results from the trials carried out by Noblet and co-workers with special attention to the estimates for the maintenance requirement expressed in ME or NE

The energy balance data from Noblet et al. (1989b) and Noblet et al. (1994) are used to derive a new NE formula of CVB. In both of these papers the NE value of the diets was calculated using a NE value for maintenance of 749 kJ NE per $kg^{0.60}$.The origin of this figure is a regression model: HP = a * BW ^{b} + c * ME, where a is an estimate for FHP, b the exponent for body weight and c the inefficiency of energy retention ($1\text{-}k_g$). Additionally, a data set with a wide range in body weight (20 - 100 kg) was needed to improve the accuracy of the estimate of the exponent b. The value of 0.60 for the exponent b is not discussed in these papers, but elsewhere (Noblet et al., 1989a).

The most relevant papers from the group of Noblet and co-workers are shortly described in a chronological order in the next pages. Most attention is paid to the (net) energy required for maintenance and not on technical aspects concerning the measurement of the energy balance of growing animals (RE or NEp).

3.1. *Noblet, J., Karege, C. and Dubois, S., 1989a*

Noblet et al. (1989a) proposed to express the maintenance requirement per $kg^{0.60}$ instead of per $kg^{0.75}$. In this experiment they used males, females and castrates from their experimental herd and some pigs from a commercial line with a high potential for growth. The animals were used several times during their growth from 20 to 100 kg. The used the model was:

[14] $ME = a * BW^b + c * REp + d * REf + error$

where a = MEm , BW = body weight, b = the exponent for BW, c = $1/k_p$, REp = energy retained as protein, d = $1/k_f$ and REf = energy retained as fat.

The results showed no significant effect of sex or genetic back ground on MEm and k_p and k_f. The model with the lowest residual standard deviation was:

[15] $ME = 1046 * BW^{0.60} + 1.56 * REp + 1.23 * REf$ (RSD= 595 kJ)

The conclusion from this paper was that the MEm requirement was about 1050 kJ ME per kg $BW^{0.60}$ and that the k_p was about 0.63 and k_f about 0.8. The use of a model with $BW^{0.60}$ instead of $BW^{0.75}$ increased the maintenance requirement and the partial energetic efficiency of protein deposition. Thus, the use of $BW^{0.60}$ caused a transfer of energy from the energetic costs associated with protein gain to the maintenance requirement.

3.2. *Noblet, J., Fortune, H., Dubois, S. et Henry, Y., 1989b*

Noblet et al. (1989b) presented a number of regression equations to predict Net Energy on the basis of a data set with 41 diets. In these energy-balance trials Large White boars with a body weight of about 43 kg were used. The NE value of the diets was calculated as NEm + NEp where for NEm a value of 749 kJ per $BW^{0.60}$ was used. This value was derived from this experiment and from data collected in other trials with the same genotype and sex, but with a body weight ranging from 20 to 105 kg. Noblet et al (1989b) called this value FHP, but it is a extrapolated value based on the relation between ME intake and heat production (at a ME intake equal to zero) and not a measured value.

The NEm value used in this experiment and the MEm value as derived Noblet et al. (1989a) are in line with each other when a k_m of about 0.715 is assumed. An overall efficiency for the energetic conversion of ME into NE was about 0.74. Unfortunately, estimates of k_p and k_f were not given.

Noblet et al. (1994) added 20 diets to this data set and derived from the 61 diets several equations to predict the NE value. The estimate for NEm was the same as used in the data set of 1989.

3.3. Noblet, J., Karege, C.and Dubois, S., 1991

Noblet et al. (1991) reported the results of 195 energy balance trials with pigs weighing 15 to 110 kg. There were seven groups differing in genotype and sex: Large Whites (males, females and castrates), Piétrain (males), Meishan (castrates), synthetic line (males) and Meishan *Large White (castrates). This experimental design resulted in a wide range of protein gain (56 to 150 g/d) and fat gain (145 to 303 g/d). In order to estimate MEm it was assumed that k_p was 0.60 and k_f was 0.80.

[16] $MEm = ME – REp/0.6 – REf/0.80$

According to equation [16[] the males from the synthetic line had MEm of 1048 kJ per $BW^{0.60}$ For the Large White males this value was 974 , for the Piétrain males 899 kJ and for the Meishan castrates 874 kJ. The remaining groups showed values close to 1000 kJ. In contrast to Noblet et al. (1989a) significant differences in MEm between genotypes were observed. Because visceral mass contributes substantially to MEm, it was suggested that differences in the ratio visceral mass to the body weight can influence the estimate of MEm in growing animals. Also it was suggested that behaviour and sensitivity to environment can cause differences in HP between animals of different genotype and sex.

3.4. Van Milgen, J., Bernier, J.F., Lecozler, Y., Dubois, S and Noblet, J., 1998

Van Milgen et al. (1998) used Meishan castrates, Large White castrates, Large White males and Piétrain males at a live weight of 25, 40 and 60 kg to study the effect of fasting and activity on FHP in growing pigs. The body composition in terms of muscle percentage, fat percentage and viscera percentage were estimated on the basis of data from a slaughter experiment with comparable animals. Viscera are defined as gastrointestinal tract, liver, spleen, pancreas, kidneys, bladder, heart, reproductive organs and lungs. The FHP was corrected for physical activity as measured with infrared sensors. During the analysis of the data it appeared not possible to describe resting FHP with a single predictor for all tested combinations of breed and sex. Thus, it was decided to treat the data from the Meishan castrates separately from the lean genotypes. For the lean pigs it was derived that

[17] $\text{Resting FHP} = 550 * (\text{Muscle Mass})^{0.66} + 2011 * (\text{Viscera Mass})^{0.66}$.

The exponents for muscle mass and viscera mass differ from the exponent for body weight. This is due to the use of two compartments instead of the total body weight. With this equation it can be calculated that the total contribution of viscera exceeds that of muscle. The heat production due to activity was in general related to the body weight, but there were differences between the groups. During fasting activity accounted for 7.9, 4.8, 4.9 and 8.3 % of the total FHP in Meishan castrates, Large White castrates, Large White males and Piétrain males respectively. The respiration quotient was for fasting about 0.73. This indicated the oxidation of fatty acids and/ or amino acids.

In the discussion it was claimed that a model with $BW^{0.60}$ instead of $BW^{0.75}$ to predict FHP resulted in a smaller residual standard error over the range of 25 to 60 kg body weight. The resting FHP for the lean pigs was estimated to be 962 kJ / $BW^{0.60}$. Comparison with other data can be hampered by the lack of a correction for activity in earlier experiments or by differences in body composition. The fact that viscera contribute substantially to FHP implies that changes in viscera weight due to feeding level or feed composition can be very important. As indicated the length of the fasting period can have an influence on FHP. A longer fasting period suggests a smaller contribution from the viscera (less weight and less activity), but results also in a situation that is less representative for a growing pig.

3.5. Noblet, J., Karege, C., Dubois, S. and van Milgen, J., 1999

Noblet et al. (1999) used the same genotype/sex combinations {Large Whites (males, females and castrates), Piétrain (males), Meishan (castrates), synthetic line (males) and Meishan *Large White (castrates)} as in Noblet et al. (1991). Besides energy balance trials during the growth from 20 to 100 kg, litter mates from the pigs were slaughtered at regular intervals in order to measure body composition. From the slaughter data allometric relationships between empty body weight and body weight and between empty body weight and body compartments such as muscle and viscera were derived. These relationships were used to predict body composition of the pigs during their energy balance measurements. The models used were:

[18] $ME = a * BW^b + 1/k_p * REp + 1/k_f * REf$

and

[19] $ME = a_m * (\text{Muscle mass})^b + a_v * (\text{visceral mass})^b + 1/k_p * REp + 1/k_f * REf$

With model [18] the estimate for exponent b was 0.601 and thus fixed at 0.60. The estimates for k_p was 0.644 and for k_f 0.83. The maintenance in kJ ME per BW $^{0.60}$ was: synthetic line males 1122 and Piétrain males 998, all the Large Whites 1068, Meishan * Large White castrates 1093 and Meishan castrates 936. This model showed a considerable lower residual standard error than a model with BW $^{0.75}$.
When model 19 was applied, the exponent b was 0.70. This value is more or less in line with the value of 0.66 in equation [17]. The estimates for k_p was 0.629 and for k_f 0.814. The maintenance was estimated to be 539 kJ ME *(kg muscle mass) $^{0.70}$ and 1788 kJ ME*(kg viscera mass) $^{0.70.}$ To decrease the residual standard error an additive group effect was needed: for the synthetic line males (+ 723 kJ/d) and for the Large White male (-457 kJ/d) and Meishan* Large White castrates (+609 kJ/d). This correction was equal to 2 to 3 % of the total ME intake.
In the discussion it is suggested that MEm is defined at a “normal” level of activity, but that these animals should have lower activity than group-housed animals and that MEm might be underestimated.
The use of a model with MEm per BW $^{0.60}$ does raise the total maintenance requirement in kJ/d. Because the total heat production is a measured value, the estimates for k_p and k_f must increase.
The use of muscle mass and visceral mass could not exclude the need to use some correction factors for some groups. It is suggested that there is some difference in the metabolic activity of different organs between specific breeds / sex combinations. Surprisingly, a possible difference in physical activity between the breeds / sex combinations is not mentioned as an explanation of the present results.
In conclusion the use of MEm per BW $^{0.60}$ or MEm calculated with muscle mass and visceral mass is preferred over the use of instead of MEm per BW $^{0.75}$

3.6. Van Milgen, J. and Noblet, J., 1999

Van Milgen and Noblet (1999) proposed another statistical analysis of energy balances trials than the classical model as shown in equation [18]. The data from Noblet et al. (1999) were used in this article. In this new model it is assumed that the amount of energy for protein deposition has a linear relation with the body weight and that MEm can be described as a * BW^b or as $a_m * (\text{Muscle mass})^b + a_v * (\text{visceral mass})^b$ and that the remaining energy is stored as fat. It is known that growing animals fed at maintenance retain some energy as protein and mobilise some body fat. To correct for this phenomena a small correction factor was introduced which was related to body weight. At a body weight of 300 kg this correction factor becomes equal to zero. This multivariate model resulted in lower estimates for maintenance and for k_p than Noblet et al. (1999). After some rearrangements in the model it was possible to calculate NEm (assumed to be equal to FHP) on the basis of a number of parameters. The estimate of NEm for a pig of 50 kg ranged between 630 and 730 kJ, depending on the combination of breed and sex. In the discussion the model was extended to cover also situations in which maximum protein deposition is reached.

The concept of a maintenance requirement in growing animals remains very complicated. On one hand it is suggested to ignore the experimental data and to define that protein and lipid deposition are equal to zero at maintenance level. On the other it is suggested that there are curvilinear relations between energy intake and the deposition of protein and fat above maintenance.

3.7. Van Milgen, J., Quiniou, N., and Noblet, J., 2000

Van Milgen et al. (2000) used castrated Large Whites, Piétrain * Large White castrates and Piétrain * Large White males in an experiment with different feeding levels (0.7, 0.8, 0.9 and 1.0 of ad libitum feed intake). The model of van Milgen and Noblet (1999) was adapted by the use of non-linear functions between ME intake and protein (and lipid) deposition. The results showed that the MEm is about 850 kJ ME per $BW^{0.60}$ and k_p was estimated to be 0.56 and k_f 0.75. The lower value for MEm is explained by the use of several levels of feed intake. A lower feed intake implies a lower visceral mass and thus a lower MEm. This means also that MEm depends on the experimental design and the model used for its calculation. Due to the lower MEm, also the partial energetic efficiencies for protein gain and fat gain were lower. In the discussion it is stated that MEm in growing pigs is not equal to the amount of ME required to realise an energy balance of zero due to the process of protein gain and fat mobilisation. However, this discrepancy was too small to include it in the present model. Moreover, the presented model using individual housed pigs cannot be applied directly in practice due to the known effects of group-housing conditions on voluntary feed intake and on social interactions between pigs.

3.8. Noblet, L., Le Bellego, L., van Milgen, J. and Dubois, S. 2001.

Noblet et al. (2001) studied the effect of reducing protein level (with supplying sufficient essential aminoacids) and the addition of fat in growing pigs. The idea was that low protein diets and high fat diets should generate less heat. This can be of interest in countries with high temperatures. The animals were crossbred barrows (Piétrain * (Landrace* Large White)) of about 60 kg body weight. In these energy balances also physical activity (force sensors) and feeding behaviour were measured. Because the animals were fasted during the last two days of an experimental period, it was possible to split total heat production into four components: the short-term thermic effect of the feed (TEFst), the long-term thermic effect of the feed (TEFlt), heat production due to activity (HPac) and FHP. Net Energy was calculated as the sum of RE and FHP adjusted for activity.

FHP was about 765 kJ per $BW^{0.60}$ and HPac was about 200 kJ per $BW^{0.60}$. Low protein diets showed a lower total HP and a higher RE. The highest RE levels were seen in the pigs with low protein and increased fat percentage.

The ratio between NE measured / NE predicted (according to Noblet 1994) was 0.97 or 0.98 on the high protein diet and increased to 1.01 or 1.02 on the low protein/high fat diet. Thus it seems that NE value of protein is overestimated and that of fat is underestimated.

3.9. Le Bellego, L., Van Milgen, J., Dubois, S.and Noblet ,J., 2001

Le Bellego et al. (2001) describe partially the same experiment as Noblet et al. (2001). However, in this paper only the effect of lowering crude protein of diet is studied in three experiments. Because there is much overlap in the used material it not surprising that FHP is also close to 750 kJ per $BW^{0.60}$. The pigs used about 8% of their ME intake for physical activity. The ratio between NE measured / NE predicted (according to Noblet 1994) was 0.98 on the high protein diet and increased to 1.01 on the low protein. This effect was not statistical significant.

3.10. Quiniou, N., Noblet, J. , van Milgen, J. and Dubois, S. 2001

Quiniou et al. (2001) studied the heat production of group-housed growing pigs under different ambient temperatures. In these experiments Piétrain * Large White barrows we used varying in body weight between 30 and 90 kg. The total HP was split in four components as indicated by Noblet et al. (2001). The HPact was about 13 % of total HP at temperatures around 20^{o} C and increased at higher and at lower temperatures to 17% of total heat production. The lower critical temperature was 24^{o} C and this value is higher then the old literature references. This can be due to differences in insulation (less back fat and a higher sensitivity to cold in modern pigs). It was also shown that the LCT did not vary with body weight. It was indicated that the evaporative critical temperature is close to the value of 25^{o} C. This implies a very narrow zone of thermal comfort for the growing pigs.
In this experiment MEm was 970 KJ ME per $BW^{0.60}$.

3.11. Van Milgen, J., Noblet, J. and Dubois, S., 2001

Van Milgen et al. (2001) studied the energetic efficiency of starch, protein and lipid utilization in growing pigs. Crossbred barrows (Piétrain * (Landrace* Large White)) with a body weight of about 60 kg were used in this experiment. A basal diet was mixed with starch, starch + unbalanced protein, starch + balanced protein or starch + fat.
The total heat production was split in four components (FHP, HPact, TEFst and TEFlt). FHP was ranging between 734 to 798 kJ per $BW^{0.60}$. HPact was close to 200 kJ per $BW^{0.60}$. Using some assumptions, rather variable k_m values were calculated. This was explained by the fact hat FHP is related to nutritional history (feeding level) and that there may exist a difference in mobilised tissues (fat /protein) between growing and adult animals. There is no general agreement about the concept of maintenance. This is complicated by differences in experimental conditions and practice and by variation in physical activity between individual pigs. The authors preferred FHP as an indicator for activity free maintenance energy requirement. The physical activity remains an important source of variation in total HP. This activity can be influenced by housing conditions, feeding level, ambient temperature and genetic background.
The use of a value of 750 kJ per $BW^{0.60}$ as NEm resulted in energetic efficiencies for starch (0.84), protein (0.52) and fat (0.88) that were comparable to those as used by Noblet et al. (1994). The diet with the unbalanced protein revealed a lower NE value for protein. This seems logic because there is evidence that the NE value for protein is higher when it is used for protein deposition compared to purposes such as generation of ATP or lipid deposition. The MEm value in this experiment is calculated to be about 850 kJ per $BW^{0.60}$. This rather low value was explained by the use of different feeding levels. With ad libitum feed intake they expect a level of about 1 MJ per $BW^{0.60}$. The presented method to calculate MEm is remarkable:

[20] $MEm = FHP / k_m + HPact$

where $k_m = k_{diet} / k_{br}$
MEm equals about 850 kJ, FHP is 750 kJ and HPact has a value of about 200 kJ. This implies that k_m has a value of 1.15. This fits with the reported values of 0.616 for k_{br} and of 0.707 for $k_{basal\ diet}$. The value of 1.15 for k_m is not realistic. A high value of k_m close to 1.0 results in a MEm of at least 950 kJ ME. Such a value comes much closer to earlier reported values.

3.12. Le Goff, G., Dubois, S., van Milgen, J., Noblet, J., 2002

Le Goff et al. (2002) studied the effect of dietary fibre on the metabolic utilisation of energy in growing and finishing pigs. In this experiment maize bran was used as source of dietary fibre. Piétrien x (Large White x Landrace) barrows were fed restricted and used at a body weight of about 40 kg and 75 kg body weight in respiration trials. Mean FHP was at zero physical activity 724 kJ per BW$^{0.60}$This value for FHP is somewhat lower than in other experiments, but that is explained by the lower feeding applied in this experiment.
The dietary fibre didn't influence FPH, nor HP due to physical activity.

3.13. Noblet, J., Van Milgen, J., Carré, B., Dimon, P., Dubois, S., Rademacher, M. and van Cauwenberghe, S., 2003

Noblet et al. (2003) presented a short paper studying the effect of body weight and protein content of the diet on energy utilisation in growing pigs. At a mean body weight of 27, 57 and 89 kg they observed a FHP of 661, 765 and 774 kJ NE per BW$^{0.60}$, respectively. The level of protein supply didn't affect the FHP.

3.14. De Lange, K., van Milgen, J., Noblet, J., Dubois, S. and Birkett, S., 2006

De Lange et al. (2006) studied the effect of feeding level on FHP using growing finishing pig between 45 and 90 kg. A FHP of 729 kJ per BW$^{0.60}$ was determined at a high feeding level of 2543 kJ ME per BW$^{0.60}$ and a value of 609 kJ per BW$^{0.60}$ was seen at a low feeding level of 1552 kJ ME per BW$^{0.60}$. Especially the FHP at the high feeding level is in line with previous observations.
However, the linear regression between ME intake and HP was (in kJ per BW$^{0.60}$) :

[21] $HP = 489\ (se = 69) + 0.368 \times ME$

Equation 21 indicates a maintenance requirement of 489 kJ and an inefficiency of 36.8%.The extrapolation to ME intake of zero is rather inaccurate due to the huge difference of the lowest level of ME intake (1552 kJ ME per BW$^{0.60}$ and Y-axis (0 kJ ME per BW$^{0.60}$).
It is concluded that the feeding level previous to the fasting period and the method of calculation can influence the estimated amount of energy required for maintenance.

3.15. Barea, R., Dubois, S., Gilbert, H., Sellier, P., van Milgen, J. and Noblet, J., 2010

Barea et al. (2010) studied the effect of residual feed intake on energy utilisation in growing pigs. The pigs were selected for 6 generation for a low or a high residual feed intake and energy metabolism was measured at 32, 59 and 88 kg of body weight. The FHP was lower in the line with a low residual feed intake compared to the line with a high residual feed intake (respectively 771 kJ and 846 kJ per BW$^{0.60}$). The mean FHP for the different body weights ranged between 911 kJ per BW$^{0.60}$ at 32 kg and 669kJ per BW$^{0.60}$ at 88 kg and the NE/ME ratios were respectively 0.783 and 0.723.

4. Discussion

4.1. *The expression of metabolic body weight*

There was doubt about the use 0.75 as an exponent to express metabolic body weight of growing pigs. Several data from Noblet and co-workers show clearly that the use of the exponent of 0.60 for growing pigs results in smaller residual standard errors in the weight range between 20 en 100 kg. However, Noblet indicated that the use of 0.75 remains valid for heavier animals.

Theoretically, the discrepancy between growing pigs and older animals may disappear when muscle mass and visceral mass should be used instead of body weight. However, the use of these two groups of metabolic active tissues is scientifically of interest, but seems not very practical to apply on a farm. Besides this practical objection, there is some evidence that the metabolic activity of the visceral mass is dependent of the feeding level and that the metabolic activity can differ between organs.

Because growing animals are used for feed evaluation, the use of the exponent of 0.60 seems sound.

4.2. *The use of MEm and k_m to derive NEm*

The estimate of MEm is directly related to the assumed or observed values for k_p and k_f. A high MEm is associated with high partial efficiencies. When RE is plotted against ME, the distribution of the observed values determines whether the inefficiency of energy retention is incorporated in a high maintenance or in a low partial efficiency. This phenomenon can be seen when Noblet et al. (1989a) is compared with Van Milgen et al. (2000) (see Table 1).

Tabel 1 . Comparison of estimated MEm, k_p and k_f values in two trials

	Noblet et al. (1989a)	Van Milgen et al. (2000).
MEm	1050 kJ per $BW^{0.60}$	850 kJ per $BW^{0.60}$.
k_p	0.63	0.56
k_f	0.8	0.75

When values for k_p and k_f are fixed, then a difference in MEm can be seen between different breeds and sex combinations (Noblet et al., 1991, 1999). This can be explained by differences in amount of visceral tissue and muscle mass or by a difference in physical activity. The physical activity can substantially contribute to the MEm as values of about 200 kJ per $BW^{0.60}$ are reported ((Noblet et al., 2001; van Milgen et al., 2001). As physical activity can be influenced by factors such as housing system, feeding level and ambient temperature and genetic background, it becomes difficult to compare different trials. The situation on farms can show even much more variation than under experimental conditions.

The use of MEm and a value of k_m to calculate a NEm value is a complicated and difficult process since it depends also on feed composition. And it must be realised that in the classical concept FHP is required to make an estimate of k_m (= FHP/MEm)

The use of MEm, k_p and k_f is only sound, when they are derived from the same data set. NEm can only be calculated when also FHP is known. As indicated before, FHP is influenced by feeding level in the period before the measurement because visceral mass is related to the ingested amount of feed. The influence of dietary composition on FHP is unknown. Possibly the well known relation between NSP in the diet and the endogenous protein secretion has also an impact on the measurement of FHP. However, this effect was not shown by Le Goff et al (2002) using maize bran as dietary fibre source.

Theoretically it is possible to define all kinds of factors that influence FHP, but most of these factors will complicate a feed evaluation system dramatically.

4.3. The use of FHP as an indicator for NEm

Thus, it seems much easier to state that FHP can be used as an indicator for NEm. As explained, FHP includes the inefficiency of the conversion of body energy into the true NE for maintenance. A high efficiency (k_r) results in a small the discrepancy between FHP and the “true” NEm. On the other hand, FHP includes physical activity as shown by Noblet et al. (2001). Thus, if possible, FHP should be corrected for physical activity or should be measured at a constant level of activity. Also the duration of the fasting period and ambient temperature can affect the FHP. Thus, if FHP is used as an indicator for NEm, the measurement of NEm should be standardised as much as possible.

The value for NEm of about 750 kJ per $BW^{0.60}$ as given by Noblet et al. (1989b) is confirmed by Noblet et al.(2001), van Milgen et al. (2001) and Noblet et al. (2003) after correction for physical activity. Le Goff et al (2002) observed a somewhat lower value due to a lower feeding level. Also, de Lange et al. (2006) reported somewhat lower levels for FHP in an experiment with different feeding levels. Barea et al (2010) reported a rather wide range for FHP (669 -911 kJ per $BW^{0.60}$). The level of 962 kJ per $BW^{0.60}$ for FHP corrected for physical activity (Van Milgen et al., 1998) remained surprisingly high.

The use of FHP (corrected for physical activity) as an indicator of NEm is simple and relatively easy to measure in growing animals without assumptions. The heat production due to activity (within the zone of comfort) is a loss and in a NE evaluation system it is not necessary to attribute this loss to the inefficiency due to maintenance or growth (NE = NEm + NEp).

5. General conclusion

There is evidence that the expression per kg $^{0.60}$ is more suitable for fast growing, lean pigs than the traditional expression per kg $^{0.75}$. The use of FHP as an indicator for NEm has the advantage that it is a measurable value. In several experiments the value of about 750 kJ per kg $^{0.60}$ is observed (Table 2). The choice of the level of NEm influences the level of NE, but has hardly any effect on the ranking of individual feed stuffs (Noblet et al., 1994). The use of MEm and k_m has no additional value because k_m is strongly related to FHP and can only be used in combination with partial efficiencies for k_p and k_f from the same data set (Table 3)

Table 2. Overview of results of Noblet with respect to estimates of NEm

source	**NEm (kJ/BW$^{0.60}$)**	**remarks**
Noblet et al., 1989b	749	Regression of RE on ME
Van Milgen et al., 1998	962	FHP, corrected for activity
Van Migen and Noblet, 1999	630-730	Data set of Noblet et al. 1999
Noblet et al., 2001	765	FHP, corrected for activity
Le Bellego et al, 2001	750	Data set of Noblet et al., 2001
Van Milgen et al., 2001	734-798	FHP, corrected for activity
Le Goff et al, 2002	711-743	FHP, corrected for activity
Noblet et al, 2003	661-774	FHP, corrected for activity
De Lange et al, 2006	609-729	FHP, extrapolated plateau

Table 3. Overview of results of Noblet with respect to estimates of MEm, kp en kf

source	**MEm (kJ/BW$^{0.60}$)**	**k_p**	**k_f**
Noblet et al., 1989a	1046	0.63	0.80
Noblet et al., 1991	874 - 1048 [1]	0.60 [2]	0.80 [2]
Noblet et al., 1999	936 - 1122 [1]	0.64	0.83
Van Milgen et al., 2000	850 [3]	0.56	0.75

[1] different genotypes
[2] fixed values in order to estimate MEm
3 lower feeding level

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