CHAPTER II
LITERATURE REVIEWS

2.1 Beef cattle production

2.1.1 Beef cattle stock and beef population in the world

Beef cattle populations around the world reflect the areas of feed available in each country. The beef cattle populations in some parts of the world are shown in Figure 2.1. According to FAO statistics (2009), Asia had the second largest beef cattle population following America. The Asian population of beef cattle and beef production have both increased in their share of the world market, and Asia beef has been more involved in international trade in recent year. In South-East Asia, Thailand has the second largest beef cattle population after Myanmar (FAOSTAT, 2009). Beef cattle in Thailand represents 21% of the South-East Asia population followed by Vietnam (20%), Cambodia (11%), Lao (5%) and Malaysia (2%). The tendency is for beef cattle numbers to increase with rising human population, increasing per capita incomes, changing technologies and availability of new techniques for management (Templeton and Scherr, 1997; Sorensen et al., 2006).

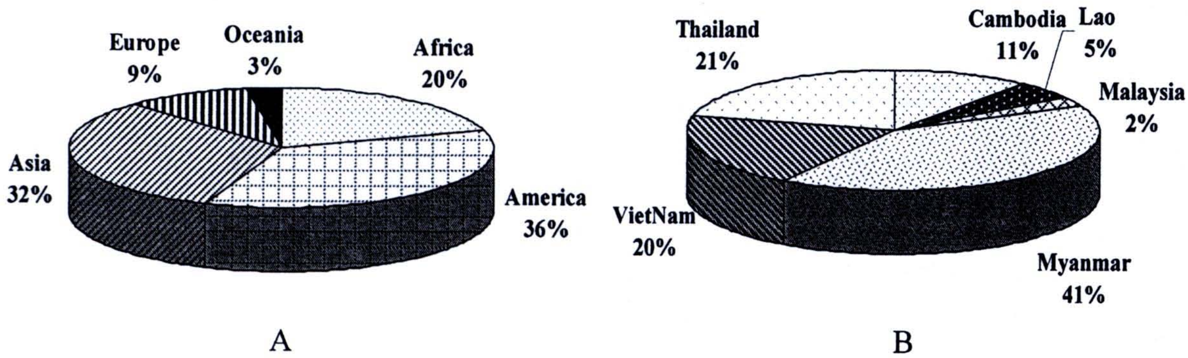

Figure 2.1 The beef cattle population in the world (A) and beef cattle population in South-East Asia (B) in 2008 (FAOSTAT, 2009).

2.1.2 Beef cattle stock and population in Thailand

Thailand is a primarily an agricultural country. Expansion in livestock farming is very important, involving of 70% of population. Beef cattle are one key farm animals, which are firmly, merged into trade, industry and rural life. They are multiple purpose serving as draught power, meat or milk for home consumption and as a source of income (Na-Chiangmai, 2002; Chantalakhana and Falvey, 2008). A rise in demand for export cattle in 1920s resulted in a three-fold increase in cattle prices which also resulted in changes in many of main applicable technologies and farm organization under the government distribution to fulfill the modernized beef industries (Lindsay, 2000; Abdullahi et al., 2002). This reason may lead to the improvement in cattle production and increasing cattle population in Thailand.

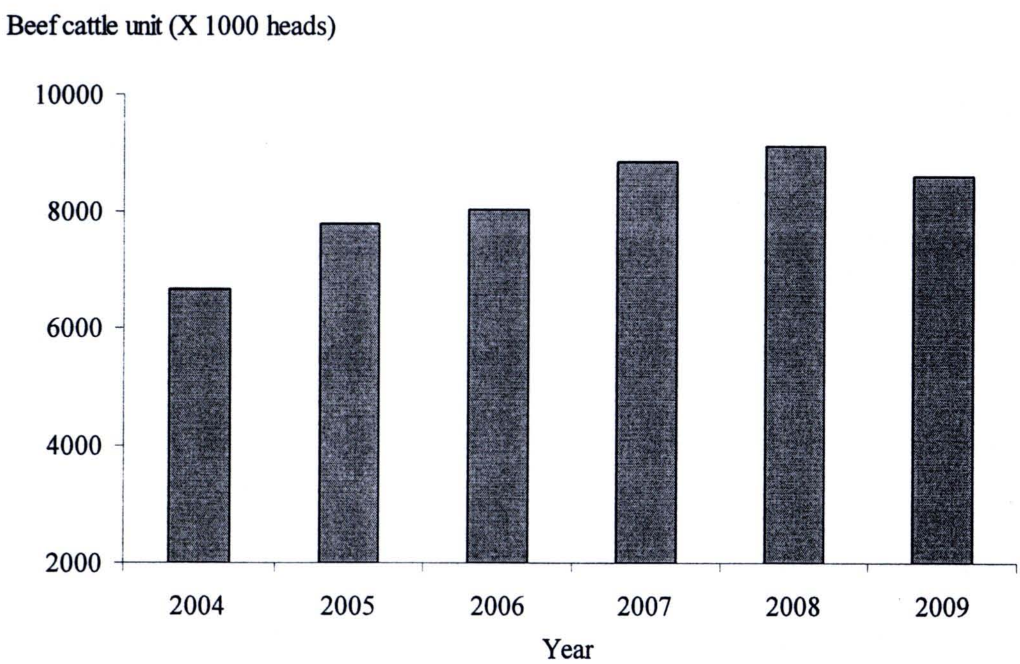

Figure 2.2 The beef cattle population in Thailand by year from 2004-2009 (adapted from DLD, 2010)

According to DLD statistics (2010), from 2004 to 2008, the numbers of beef cattle increased 36% from 6,668,332 head in 2004 to 9,112,093 head in 2008. However, in 2009, the beef population decreased 5.67% (8,595,428 heads). The cattle stock data are shown in Figure 2.2. The rapid growth in cattle numbers in the last decade has been caused by the government supporting a plan for problem alleviation of the smallholder beef farmer (one million beef cattle farmers).

During the past 5 years, the country's beef cattle populations have increased rapidly. Total farm households with beef cattle were 1,226,005 families, with the average number of cattle per farm being 6.55 head (Khemsawat and Phonbumrung, 2008). This data indicates that most of the beef cattle production in Thailand is derived from small-holder farmer or small farms industry. The highest numbers of beef cattle farmers are in the North-Eastern region followed by South, North and Central region of Thailand (Figure 2.3). Because of the limited area, farms are relatively small in size and generally practice mixed farming with crops as a major component and livestock to provide draught power and manure as well as cash income (Abdullahi et al., 2002).

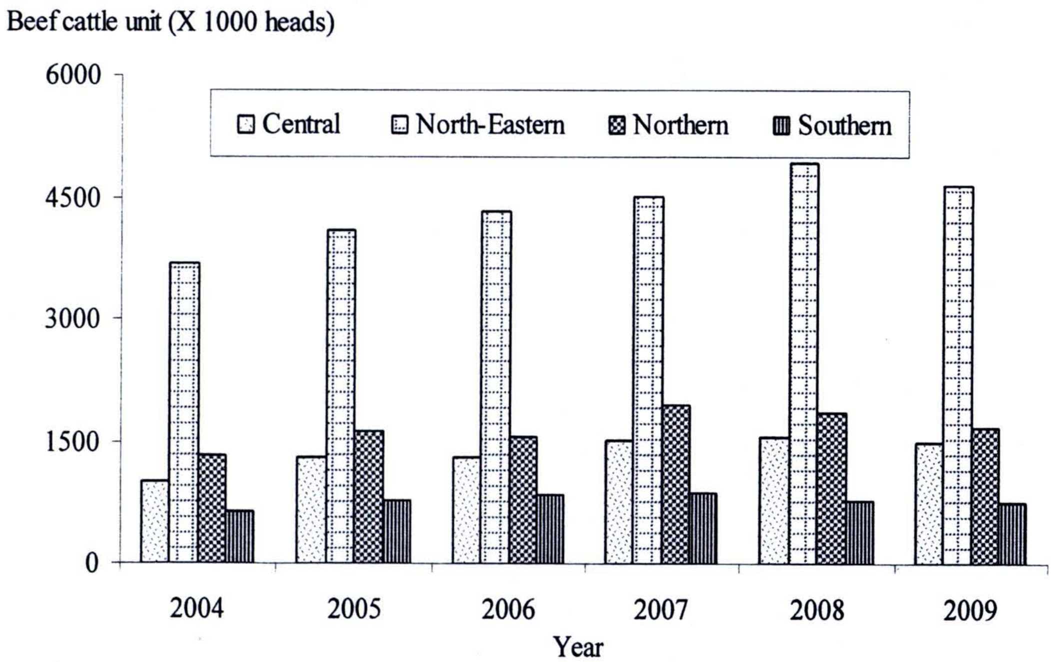

Figure 2.3 Beef cattle population in Thailand by regions from 2004-2009 (adapted from DLD, 2010)

Beef cattle found in Thailand have been classified as Thai native cattle and exotic purebred or crossbreds. Thai native cattle, which is *Bos indicus* genotype sometimes known as humped cattle, originated in South Asia and later spread across South-East Asia (Maule, 1990; Jaturasitha et al., 2009) They are a local breed, representing around 70% of the country's beef cattle herd (DLD, 2010). They are usually quite light, smaller mature body size and grow at a slower rate compared to European breeds, but they have adapted to high temperature, tolerate harsh sunshine, resist parasites and utilize poor quality diets of the humid tropical zone. In small-holder farmer, they are regularly utilized as meat or draft animals.

Table 2.1 Thai native cattle and exotic purebred or crossbred beef cattle populations in Thailand (2002-2009)

Year	Number of cattle (heads)	
	Thai native cattle	Exotic purebred or crossbred cattle
2002	3,637,640	1,912,545
2004	4,907,289	1,761,039
2006	5,655,470	2,380,587
2008	6,365,620	2,746,473
2009	5,442,415	3,153,013

Source: DLD (2010)

The populations of Thai native cattle from 2002 to 2009 are shown in Table 2.1. During 2002 to 2008, Thai native population steadily increased, but the trend was reversed to a decline in 2009, whereas the exotic purebred or crossbred population continued increasing.

2.1.3 Current circumstances of beef production in Thailand

Meat adequacy is dependent on the balance between domestic consumption and production (Rutherford, 1999). Increasing trends in the demand of beef and beef products on a per capita basis is a major effect of economic development, progressing urbanization and sizeable population growth (Chantalakhana, 1996; Khemsawat and Phonbumrung, 2008). In the past 5 years, beef cattle production in Thailand has always been outstripped by the consumption demand. From this situation, rising excess demand in the country has resulted in increasing import value of beef especially in frozen form. The meat import values increased from 158 million baht in 2004 to 394 million baht in 2008 (Figure 2.4). In the future, the meat demand is likely to continue to increase as a result of population growth and it will outstrip supply. Therefore, the need for beef cattle production to meet consumer demands is critical to maintain a beneficial and sustainable beef industry in the country. The potential for beef production development remains brilliant considering the manpower, grazing lands, feed, animal base, technology, resources available and strong ability of human resources engaged in cattle research and development (Casillo, 2000). Chantarakhana and Skunmun (2002) and Lindsay (2000) suggested that when small-holder farmers change to more intensive commercial production, the feed supply will become a major problem. High performance beef cattle need a high quality diet. Programs to lower the cost of feed and make more use of local feed resources can be very helpful in improving small farm efficiency (Liang and Young, 1995).

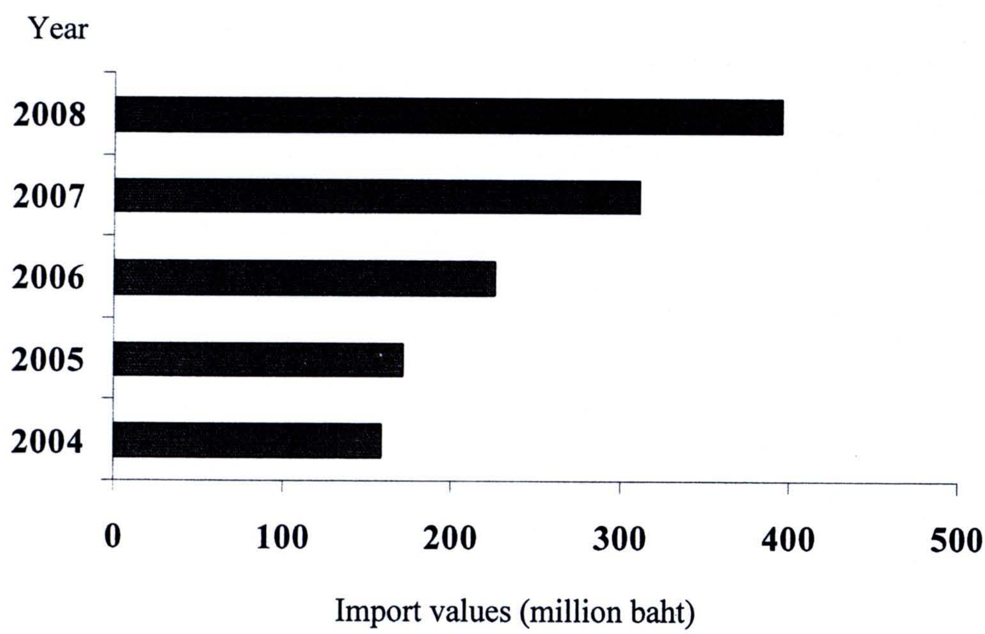

Figure 2.4 The frozen beef import values of Thailand by year from 2004-2008 (adapted from DLD, 2009)

2.1.4 Problems of beef cattle production and development in Thailand

The North-Eastern region of Thailand has the largest population of beef cattle. This region has lesser amount of rainfall, normally poor quality soils, and limited irrigation. In addition, the average farmer was of low income, depending for their living on rain-fed rice production (Na-Chiangmai, 2002; Chantalakhana and Falvey, 2008). The farmer's main purposes in keeping beef cattle are for draught power and manure as fertilizer for paddy fields (Indramangala et al., 2001). Beef cattle are usually maintained on a low to medium plane of nutrition and concentrate feeding is minimal. The production of improved meat quality is not the primary focus of the small holder farmer. This is the reason for limited commercial production of beef. Furthermore, there are still many factors influencing beef cattle production and development such as low quality of feedstuffs (Kawashima et al., 2000), limitation of breeding plan (Na-Chiangmai, 2002), high feeding cost for production and lack of market incentive (Davendra, 2001; Chantalakana and Skunman, 2002). All of these problems are similar to those reported by DLD (2005), which concluded that the major problems of beef cattle production are lack of high quality grassland and feedstuffs, limited farm management skills and lack of a suitable breed for the village environment. However, the improvement of small farm enterprises has been most successful when farmers could be persuaded to focus on high quality production and practice skills in farm management. These strategies are being used to enhance beef efficiency and will make the industry more sustainable.

2.1.5 Future trend for beef cattle development

Nowadays, the demand for meat consumption has been increasing due to increasing standard of living and education. This has caused meat production to be insufficient for consumption requirements. In addition, approximately 85% of beef cattle are raised in small farms, which are very different in patterns of husbandry and management from region to region and even from farm to farm (DLD, 2010; Indramangala et al., 2001). The knowledge for raising cattle has been passed down through each generation of farmers. Most beef cattle are tethered and graze along roadsides or waste land. The scarcity of fodder and pasture in the dry period are major problems and can be assumed to be even larger if numbers of cattle continue to increase (Chantalakhana and Falvey, 2008). Low quality roughage and agro-industry by-products are being used to replace animal feeds, resulting in low animal performance. Therefore, better feed management is one key to more successful improvement of farm benefits and declining feed cost in farm business.

Currently, farmers generally use NRC or ARC guidelines to formulate diets and evaluate feeding programs in Thailand. While nutrient needs of local beef cattle fed under humid tropical conditions probably differ from feeding guidelines of temperate breeds from NRC or ARC because of diverge in genetics, mature size, quality of feed, climatic conditions and nutrient utilization, (Ferrell and Jenkins, 1998; NRC, 2000; Paul et al. 2003). There is still a lack of information on beef cattle requirements in Thailand. This is a restriction for assessing feeding programs in beef production. Therefore, the establishment of feeding guidelines for beef cattle are an urgent requirement to move towards the sustainable development of beef production. The future research should primarly focus on nutrient requirements of beef cattle using locally available feed resources in Thailand.

2.2 Energy system for ruminants

Energy is an organic nutrient, which is essential for human and animal bodies. Animals require energy to do work, maintain tissue, thermoregulation and to synthesize products such as meat, eggs and milk. Energy requirements of animals differ according to physiological functions, body size and environmental conditions (Johnson et al., 2003; Ferrell and Otjen, 2008). Insufficient energy may reduce or halt growth especially in skeleton growth, and cause body weight loss, failure to conceive and increased mortality (ARC, 1980; NRC, 2000).

2.2.1 Units of energy

Energy may be defined in several different units. The international System of Units (SI) and the National Bureau of Standards (U.S.A.) express electrical, mechanical, and chemical energy as the number of joules (J). This unit is commonly used in nutritional studies or energetic efficiency of animals (Blaxter, 1987; NRC, 2000). Another unit of energy is the watt (W) and the calorie. The watt is a unit of power. 1 watt has been standardized to equal 1 joule per second, whereas, the calorie is being phased out in the scientific community. One calorie is to equal to 4.184 joules and which is approximately equal to the heat required to raise the temperature of 1 g of water from 16.5 °C to 17.5 °C (McDonald et al., 2002; NRC, 2000). In nutritionists work, both the joule and the calorie are so small that they are expressed as multiple units: kilojoules (KJ) and mega joules (MJ) are 10^3 and 10^6 times higher than one joule, respectively (ARC, 1980; WTSR, 2008). The kilojoules unit is generally used to describe the daily energy requirement of an animal for maintenance and growth (Brody, 1999).

2.2.2 Energy partition

The animal derives energy from food. During digestion and absorption, energy portion in chemical food compound (chemical energy) is converted into heat energy by nutrient catabolism. The energy partition and loss of energy in animal metabolism is shown in figure 2.5. The quantity of heat per unit weight of food resulting from organic substance completely oxidized to carbon dioxide and water is known as the gross energy (GE) (NRC, 2000; Pond et al., 2005). Of the gross energy of foods, not all is obtainable and useful to the animal (Johnson et al., 2003; Williams and Jenkins, 2003). A quantity of energy is lost from the animal in the form of solid, liquid and gaseous excretion; another part is lost as heat (Blaxter, 1987).

Gross energy (GE) is measured in an apparatus known as a bomb calorimeter, which in its simplest form consists of a strong metal chamber resting in an insulated tank of water. The quantity of heat produced is then calculated from the rise in temperature and the weights and specific heats of water and the bomb. The bomb calorimeter can be used to determine the gross energy content in foods and animal tissues (Blaxter, 1987; McDonald et al., 2002).

Digestible energy (DE) is calculated from the quantity of gross energy minus energy loss in feces (FE). As the small portion of feces energy loss is comprised of endogenous mucosa and micro flora fragments, therefore the energy values from this calculation represent the apparent digestible energy. NRC (2000) suggested that digestible energy as a proportion of gross energy may vary from 0.3 for very mature, weathered forage to nearly 0.9 for processed, high-quality cereal gains. Digestible energy has some value for feed assessment because it reveals diet digestibility and can be measured with relative ease (Pond et al., 2005). However, digestible energy does not properly account for several major losses of energy related with digestion and metabolism of food (Johnson et al., 2003; NRC, 1981; NRC, 2000).

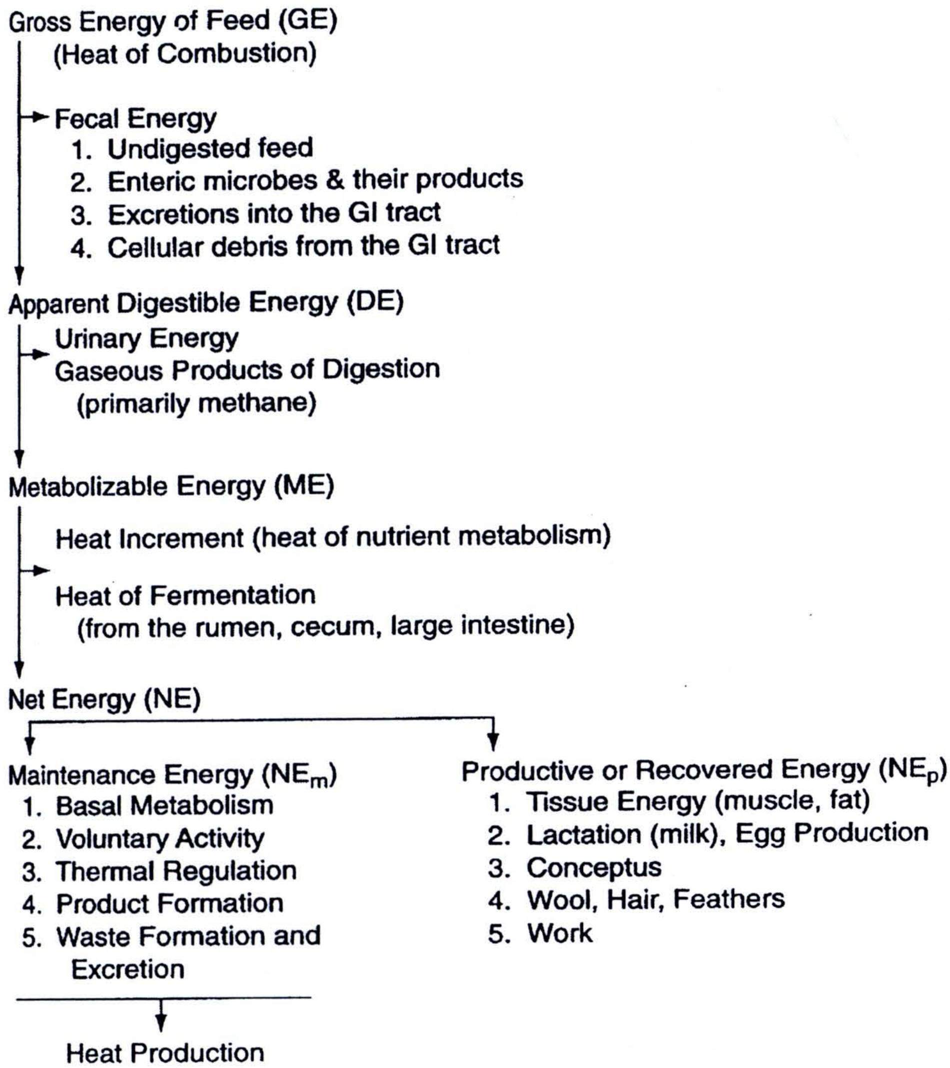

Figure 2.5 The energy partition and loss of energy in animal metabolism
Source: Pond et al. (2005)

Metabolizable energy (ME) can be defined as the energy remaining after digestion and absorption. Ferrell and Oltjen (2008) refer to metabolizable energy, which is the energy available to sustain the body functions of an animal together with minimum activity and heat increment (HI). The metabolizable energy is determined from the quantity of digestible energy minus urinary energy losses and energy losses in methane production (Kroman 1973; Johnson et al., 2003). The energy loss in urine is present in nitrogen-containing substances and also non-nitrogenous compounds (Brody, 1999). Typically, energy loss from both urine and gas together is 18% of digestible energy, therefore the following equation was derived so metabolizable energy and digestible energy could be related using metabolizable energy = 0.82* digestible energy (NRC, 1996; Pond et al., 2005). For most forage, mixtures of forages and cereal grains, the ratio of metabolizable energy to digestible energy is about 0.8 but can vary considerably (ARC, 1980; CSIRO, 1990). However, the ratio of metabolizable energy to digestible energy can vary depending on feed quality and feeding level (Garrett and Johnson, 1983; AFRC, 1993). The metabolizable energy values are rarely verified in practice, however, because only a few laboratories have the facilities and budgets to collect and analyze respiratory gases and urine (Van Soest, 1994; Pond et al., 2005).

Net energy (NE) is the ideal system of expressing the energy content of feed or energy requirement of beef cattle for a specific physiological function (Kroman, 1973; Garrett and Johnson, 1983). The net energy is energy remaining after all metabolic losses, which is calculated from the amount of metabolizable energy minus heat of fermentation and heat loss from nutrient metabolism (heat increment) (Blaxter, 1967; Lofgreen and Garrett, 1968; Ferrell and Oltjen, 2008). The net energy could be classified into two types; net energy for maintenance and net energy for production or energy retention. The net energy for maintenance is mainly used to perform work within the body and will leave the animal as heat (Yan et al., 1997; McDanald et al., 2002; Pond et al., 2005). That used for growth and fattening and for meat, milk and wool production is either stored in the body and will leave it as chemical energy, and the quantity so used is referred to as the animal's retention (Johnson et al., 2003; Ferrell and Oltjen, 2008).

2.3 Energy utilization in ruminants

The animals require energy for body functions, mechanical work muscular activity, chemical work such as the transfer of intermediate-substances to target organs and for the increased synthesis of body components such as enzymes and hormones (Pond et al., 2005). When the chemical energy of food is used for muscular and chemical work involved in maintenance, the animal does no work on its surroundings and all the energy used is converted to heat (McDonald, 2002). It is essential to realiz that of the heat production from body metabolism, which is heat used for maintenance and heat increment of food or waste energy.

2.3.1 Energy requirement theory

Johnson et al. (2003) and Williams and Jenkins (2003) explained the energy concept in general terms; the metabolizable energy consumed by the animal appears in two forms; the first is heat energy (HE) and any metabolizable energy consumed in excess of heat energy is retained as part of the body or a useful product (energy retention, ER).The part of heat energy identified by INRA (1978), ARC (1980), and NRC (1984) are basal metabolism or fasting heat production, heat of fermentation, heat of digestion, heat of formation and excretion, heat of absorption and heat of product formation. However, both heat increment and heat of fermentation can serve useful purposes to the animal when utilized in a cold environment (Blaxter, 1967; Williams and Jenkins, 2003a). The heat increment is not a constant, it depends on feed quality, feeding level and environmental conditions (Pond et al., 2005).

The relationship between energy intake and energy retention is shown in figure 2.6. When energy retention is zero, the animal is in weight equilibrium. The level of MEI at this point would be referred to ME_m (Williams and Jenkins, 2003; Old and Garrette, 1980; Ferrell and Oltjen, 2008). When MEI < ME_m, body tissues will be mobilized to satisfy the energy deficit. In the productive animal, MEI>ME_m. Therefore, the part of the remaining MEI would be recovered as "energy retention (ER)", and the remainder would be lost as heat energy. The term MEI minus ME_m is equal to the daily ME used for gain (ME_g) (ARC, 1980; McDonald et al., 2002; Williams and Jenkins, 2003; Ferrell and Oltjen, 2008).

2.3.2 Energetic efficiency of ruminants.

The difficulty of expressing the energy value of a feed as a single unit is a part of the perplexing problem (Armsby, 1919; Garrett and Johnson, 1983). The complications are the results of a complex of factors influencing the efficiencies of metabolizable energy (ME) utilization. The concept of using the efficiencies of ME utilization did not become established until the early 1960s (Garrett and Johnson, 1983; Ferrell and Oltjen, 2008). Garrette (1980), McDonald et al. (2002) and Johnson et al. (2003) summarized and classified the efficiencies of ME utilization into 2 types such as the efficiencies of ME utilization for maintenance and the efficiencies of ME utilization for growth in general. Determination of the efficiencies of ME utilization requires the data from more than one level of feeding, because the relationship between energy intake and energy balance or energy retention is curvilinear over the entire range of food intake (Blaxter, 1967; McDonald et al., 2002; Ferrell and Oltjen, 2008). The relationship between energy intakes to energy retention approximates two linear relationships, one below maintenance represented by the symbol k_m and one above maintenance shown as k_g (Old and Garrette, 1980; Williams and Jenkins, 2003).

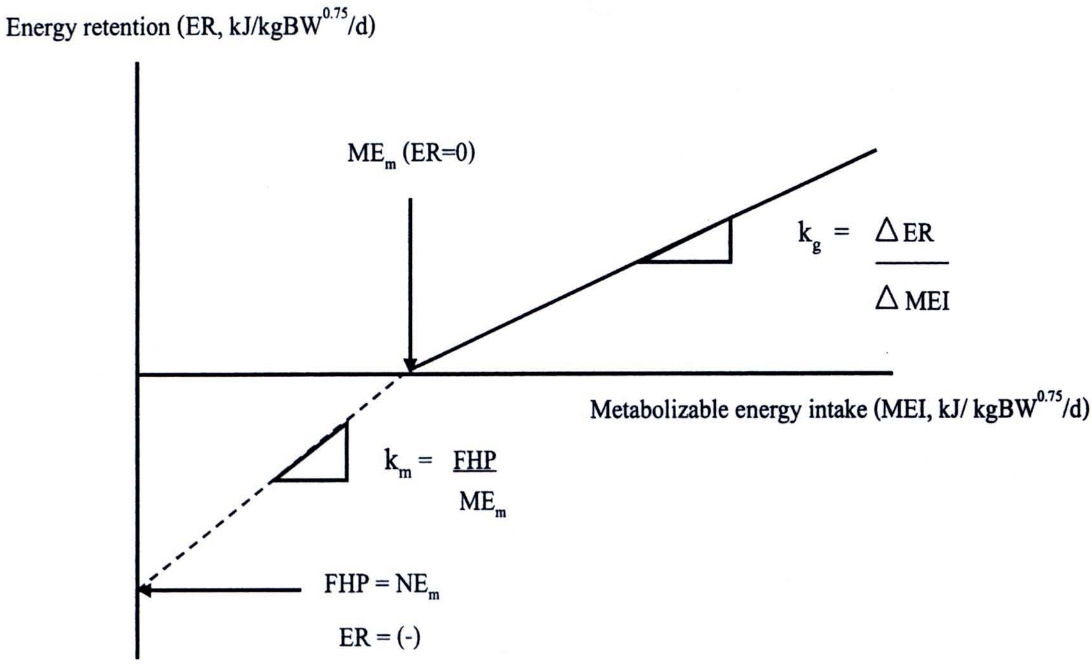

Figure 2.6 The relation between energy retention, metabolizable energy (ME) intake and fasting metabolism (McDonald et al., 2002)

The relationships of energy retention to energy intake to determine the efficiencies of ME utilization is shown in figure 2.6. The efficiencies of ME utilization for maintenance (k_m) is related to fasting heat production and calculated as the slope of the line relating energy retention to energy intake, with energy retention equal zero (k_m = FHP / ME_m). As the efficiencies of ME utilization for growth (k_g) can be estimate from the slope of the linear regression of energy retention to energy intake, with energy retention above zero ($k_g = \Delta$ ER / Δ ME).

2.3.3 Methods for determining energy requirement

NRC (2000) explains the three basic methods used to measure the energy requirement as calorimetric method (ARC, 1980), comparative slaughter (Lofgreen, 1965; Lofgreen and Garrett, 1968) and long-term feeding trials (Taylor 1981; 1986). All of these methods are used to assess the energy requirement of animals, but each approach has advantages as well as disadvantages.

2.3.3.1 Direct calorimetry method

Direct calorimeters determine the amount of total heat produced from the body and lost principally by radiation, convection, conduction. (Blaxter, 1967; McLean and Tobin, 1987). The concealed heat of vaporization is obtained mainly from the animal. The heat loss from vaporization of the animal is transferred to the air in the form of enhanced humidity and results in the enthalpy of the air being raised. Heat loss can be determined directly by using either heat skin or gradient layer calorimeters in the chamber (Blaxter, 1967; Pullar, 1969; McLean and Tobin, 1987). However, as a result of the high cost, few of direct calorimeters for farm animals are presently in use (Armsby, 1919; McDonald et al., 2002; Pond et al., 2005).

2.3.3.2 Indirect calorimetry method

Blaxter (1967), Flatt (1969) and McDonald et al. (2002) discussed about indirect calorimetry in detail and state that it is a primary procedure, based on the hypothesis that metabolic heat production is the result of oxidation of organic compounds. This technique is to estimate total heat production from the animal in the period of metabolism. In ruminants, the total heat production can be evaluated from the equation of Brouwer (1965), that is, $HE = 3.88\ 6O_2 + 1.200\ CO_2 - 0.518\ CH_4 - 1.431\ N$, where HE is heat production in kcal unit; O_2, CO_2 and CH_4 refer to gaseous exchange in liters unit; and N refers to urinary nitrogen report in grams unit. Most of the technique involves respiratory gas exchange estimation, which can be classified as confinement closed-circuit, total collection, and open-circuit systems (Abrams, 1961; Flatt, 1969; McLean and Tobin, 1987; Van Soest, 1994).

In the closed-circuit type, the animal is enclosed in a temperature-controlled chamber. Air in the chamber is nonstop flowed through an absorbent, which take outs water and carbon dioxide. Oxygen use is determined as the amount of oxygen provided to maintain pressure; the carbon dioxide yield is verified from the amount accumulated by the absorbent. Methane production is computed as the concentration difference between the beginning and the end of the test time multiplied by the volume of the system (McLean and Tobin, 1987; Johnson et al., 2003; Ferrell and Oltjen, 2008). In the total collection system, all the air used by the subject is accumulated in order to determine its volume and chemical composition (McLean and Tobin, 1987). In the open-circuit type, there are two major forms. At first, the animal breathes directly from the atmosphere and by means of a non-return valve system, expires into a separate outlet line. In the second form, the animal inspires and expires to a stream of air passing. The oxygen, carbon dioxide and methane concentration must be measured accurately in entering and outgoing air. The rate of gas consumption and gas production are calculated as the concentration difference between entering and outgoing air, multiplied by flow rate. Most calorimeters include apparatus for determining respiratory exchange and can be used for indirect calorimetry as well (Blaxter, 1967; Johnson et al., 2003; Ferrell and Oltjen, 2008).

2.3.3.3 Comparative slaughter method

The comparative slaughter method is used to estimate total body energy retention, which is accumulated in fat and protein forms (Ferrell and Oltjen, 2008). These can be measured in feeding trials if the energy content of the animal is estimated at the beginning and end of the experiment (McDonald et al., 2002). Lofgreen (1965) developed this method by separating the animals in two groups and slaughtering one group at the beginning of the trial (representing the initial group). At the end of trial, the rest of the animals are slaughtered and energy retention determined by calculating the difference between body fat and body protein quantity of initial group and final group multiplied by caloric value (9367 kcal/kg of fat and 5686 kcal/kg of protein)(Garrett, 1959). The advantages of comparative slaughter method are that animal lives in a natural condition during the experimental period with no complicated equipment, but it is expensive, laborious and destructive (Lofgreen and Garrett, 1968; Pond et al., 2005). Nevertheless, estimates of energy utilization obtained by comparative slaughter and specific gravity measurements have been used in the U.S.A. to establish a complete cattle feeding system (McDonald et al., 2002).

2.3.3.4 Carbon-Nitrogen balance method

This method is generally calculated in association with indirect calorimetric measurements (Pond et al., 2005). The procedure is based on measuring the energy retention, which is stored in fat and protein form. The mass of protein and fat accumulated can be estimated by carrying out a carbon and nitrogen balance trial. The energy retained can be determined from multiplying the mass of nutrients stored by their calorific values (Blaxter, 1967; McDonald et al., 2002). Determination of body protein accumulation is use to measure the nitrogen balance, which is estimated as the difference between nitrogen intake and nitrogen losses, then multiplying by 6.25. Body protein accretion multiplying 0.512 (assuming body protein contains 16% nitrogen and 51.2% carbon)

Carbon, which is stored as fat has been estimated by using carbon balance minus carbon accumulated as protein. This is then divided by 0.746 (assuming body fat contains 74.6% Carbon) to yield an estimate of fat accretion. Energy accretion can then be calculated from protein and fat accretion (Pond et al., 2005). The advantages of the carbon-nitrogen balance technique are that no measure of oxygen consumption is required and that energy retention is subdivided into that stored as protein and that stored as fat (Blaxter, 1967; McDonald et al., 2002). The limitation of this approach is that it is very complicated to quantify all losses of carbon and nitrogen from the animal. Therefore, this method usually results in an overestimate of energy retention because of an overvaluing of carbon or nitrogen accumulated in the animal (Pond et al., 2005).

2.3.3.5 Feeding trials method

Feeding trials are used to determine the energy requirement for growth, which requires data in different levels of feeding (Pond et al., 2005).This method can be decided with large numbers of animals. The advantage is that it is easy and it can be obtained under fairly typical production conditions (Luo et al., 2004). The maintenance values obtained very simply from this method involves the determination of the amount of food required to hold adult animals at constant weight. Allowances can be made for adjust in body weight by estimating the food equivalent of the losses or gains and correcting the observed intakes consequently (McDonald et al., 2002). Energy requirements for maintenance from feeding-trials are calculated by regression of average daily gain (ADG) and energy intake (EI). The relationship equation is as follows;

EI = a + bADG. "Maintenance" requirement is assumed to be the value at which ADG is equal to zero (Y-intercept; a) and the slope (b) of linear regressions of average daily gain on energy intake were used to describe energy requirement for "growth" (McDonald et al., 2002).

2.4 Energy Requirement of ruminants

The knowledge of energy requirement and energetic efficiency in ruminants developed via a recognized pattern of evaluation (Malone, 1994; Johnson et al., 2003). Utilization of dietary energy has been the subject of research since the eras of Lavoisier and La Place (1743-1794). In 1780, Lavoisier and La Place explained about energy of combustion, which related to energy metabolism according to the following equation; $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + heat. These laws dictate that, if one measure the heat released from total oxidation of 1 gram of carbohydrate to carbon dioxide and water in a bomb calorimeter, this result will be the same as the heat released from 1 gram of carbohydrate from combustion by an animal (Ferrell and Oltjen, 2008). Over a period of 100 years, scientists have been dedicated to verifying the relationship between gas exchange and heat production. Thus Max Von Pettenkofer (1901) tried to measure heat production by using open-circuit respiration calorimetry, while some researchers determined heat production by using close-circuit type. In concurrence with verifying the relationship between gas exchange and heat production, several groups devoted incredible energy toward devising bases for evaluation of foods that could be related to energy requirements and energy expenditure (Johnson et al., 2003; Williams and Jenkins, 2003). Armsby (1917), using respiration calorimetry defined metabolizable energy as net energy plus heat increment of feeding. Currently net energy systems are being used in United Kingdom (ARC, 1965, 1980; AFRC, 1993), France (INRA, 1978, 1989), Australia (AAC, 1990), Japan (AFFRC, 1999, 2000), developing countries (Kearl, 1982), and Thailand (WTSR, 2008). The common equation ME = ER + HE has been recognized and used as the beginning concept by energy researchers for development to the current research of NRC or ARC (Johnson et al., 2003; Williams and Jenkins, 2003; Ferrell and Oltjen, 2008).

2.4.1 Net energy for maintenance or energy for basal metabolism in cattle

Net energy requirement for maintenance (NE_m) is sometimes used as an expression of energy for basal metabolism or fasting heat production (Moe and Tyrrell, 1973; McDonald et al., 2002; Williams and Jenkins, 2003). The basal metabolism is usually described as the state of the animal which requires minimal energy to sustain the body, or the heat production of a wholly inactive animal in a post-absorptive state, within thermo neutral surroundings (Blaxter, 1967; Crampton and Harris, 1969; Pond et al., 2005). However, although this state can be accomplished in humans but, it is tremendously complicated to measure in animals. Accordingly the phrase "fasting metabolism" has been used for animals (Blaxter, 1967; Ørskov and Ryle, 1998). However, fasting heat production measurement in ruminants requires more time (at least 5 days) for the feed in the gastrointestinal tract to pass out of post-absorptive state (Blaxter, 1967; Pond et al., 2005).

The estimation of net energy requirement for maintenance necessitates determining the heat produced by the fasting animal. This heat is equivalent to the net energy that must be supplied to keep the animal in energy equilibrium (maintenance). Fasting heat production was estimated by plotting the relationship between the logarithm of heat production and metabolizable energy intake and extrapolating to zero metabolizable energy intake (Lofgreen and Garrette, 1968; Knox and Handley, 1973). However, heat production from body metabolism is related to body surface or body volume (Van Soest, 1994; Johnson et al., 2003; Ferrell and Oltjen, 2008). Body surface area is related to the square of linear size or to the two-third power of body weight ($W^{2/3}$)(McDonald et al, 2002). Therefore, the body surface of a living animal is rather complicated to determine and it is not stable. Although these various factors are involved in heat loss, they can be related reasonably well to surface area estimated by multiplying body weight (BW) by a fractional power and thus to body heat production (Blaxter, 1967, 1989). These factors led to the commonly agreed concept of metabolic weight or metabolic size ($BW^{0.75}$) (Garrette and Johnson, 1983; Kleiber, 1947 cited by Johnson et al., 2003; Pond et al., 2005)

Fasting heat production or energy requirement for basal metabolism of beef cattle suggested by Lofgreen and Garrette (1968) and NRC (2000) were 77 Kcal/kgBW$^{0.75}$ or 322 KJ/kgBW$^{0.75}$. However, there are many factors affecting basal metabolism requirement such as sex, stage, breeds, environment condition and physiological stage (ARC, 1980; CSIRO, 1990; NRC, 2000; Pond et al., 2005).

2.4.2 Energy requirement for maintenance of beef cattle

NRC (2000) defines the maintenance requirement for energy as the amount of feed energy intake that will result in no net loss or gain of energy from the tissues of the animal body. Energy requirement for maintenance consists of energy for body thermoregulation, energy for essential body metabolism, and physical activity. Estimation of energy requirements for maintenance are based on the concept of equilibrium state (energy intake at which energy retention = 0) (Blaxter, 1989; McDonald et al., 2002; Pond et al., 2005). NRC (2000) reported that the metabolizable energy requirement for maintenance represents approximately 70% of total metabolizable energy requirement for production in beef cows, which agrees with the report of Ferrell (1988), who found that the energy requirement for maintenance accounts for 60-70% of total energy expenditure. Similarly, Moe and Tyrrell (1973) reported that the energy requirement for maintenance and for growth of ruminants is approximately 70-80% and 40-60% of total energy costs, respectively. These data indicate that the energy requirement for maintenance is the main part of energy production, and it is necessary to have a thorough understanding of energy requirements in order to utilize energy feed resources with maximum efficiency. However, the maintenance requirement may vary by 10-30% because of genetic difference and diverge in nutritional conditions (Hotovy et al., 1991; Derno et al., 2005).

Over the last decade, the NRC or ARC guidelines for beef cattle production are frequently used to assess feeding programs in several parts of the world (Tedeschi et al., 2002; Chizzotti et al., 2008). Nevertheless, the energy requirement recommendation by NRC is based on *Bos taurus* beef cattle. Several researchers have suggested that *Bos taurus* can utilize low quality forage less efficiently than *Bos indicus* cattle (Ashton, 1962; Frisch and Vercoe, 1982; Hotovy et al., 1991; Ferrell and Jenkins, 1998; Chizzotti et al., 2008). Furthermore, *Bos indicus* can be adapted and perform better in a nutritionally restrictive environment than *Bos taurus* cattle. For these reasons *Bos indicus* cattle have lower maintenance requirements than *Bos taurus* cattle (Solis et al., 1988;

Carsten et al., 1989; Ferrell and Jenkins, 1998; Tedeschi et al., 2002). This suggestion is in good agreement with the report of Tangjitwattanachai and Sommart (2009), who analyzed data by using a mixed linear model (meta-analysis) and reported that the energetic efficiency for maintenance of *Bos indicus* was higher than that of *Bos taurus* by approximately 9.38 %. Moreover, this information supports the hypothesis of NRC (2000), which indicates that the energy requirement for maintenance of *Bos indicus* is assumed to be 10% lower than *Bos taurus*. However, there are few reports in the literature on the energy requirement and energetic efficiency of beef cattle in Thailand.

During the past 5 years, energy requirement studies in Thailand have been conducted on different breeds between Thai native cattle and Brahman cattle. In previous reports, Chaokaur et al. (2007) using a ventilated hood system reported that the metabolizable energy requirement for maintenance of Brahman steers fed near maintenance level was 497 KJ/kgBW$^{0.75}$/d and this result was higher than the energy requirement for maintenance of Thai native cattle as 245.18 KJ/kgBW$^{0.75}$/d from a report of Kawashima et al. (2000), who evaluated the metabolizable energy requirement for maintenance by using a ventilated flow-through method with a face mask. However, the work of Kawashima et al. (2000) does not agree with the energy recommendation for Thai native cattle by WTSR (2008), which recently reported as 484 KJ/kgBW$^{0.75}$/d and Nitipot et al. (2009)(509 KJ/kgBW$^{0.75}$/d). Later, in 2010 Tangjitwattanachai and Sommart (unpublished data) analyzed data from 7 energy trial studies of Thai native cattle in Thailand by using a mixed linear model (meta-analysis) and reported that metabolizable energy requirement for maintenance was 450.71 KJ/kgBW$^{0.75}$/d, which was slightly lower than WTSR (2008). Compared with other breeds in *Bos indicus* group, it has been found that the energy requirement for maintenance of Thai native cattle (484-488 KJ/kgBW$^{0.75}$/d) was higher than the Malaysian native cattle from the report of Laing and Young (1995) (335 KJ/kgBW$^{0.75}$/d) and Boran cattle from the report of Ferrell and Jenkins (1998) (412.96 KJ/kgBW$^{0.75}$/d), but which was similar to Brahman purebred fed under tropical conditions in Thailand from a report of Chaokaur et al. (2008) (497 KJ/kgBW$^{0.75}$/d), Tuli cattle from the report of Ferrell and Jenkins (1998) (471.53 KJ/kgBW$^{0.75}$/d) and Nellore steer from the report of Tedeschi et al. (2002) (498 KJ/kgBW$^{0.75}$/d) Furthermore, the energy requirement for maintenance of Thai native cattle was similar to Brahman crossbred fed under tropical conditions in America from a report of Ferrell and Jenkin (1998) (488 KJ/kgBW$^{0.75}$/d).

When comparing Thai native cattle with the *Bos taurus* cattle from several reports, it can be seen that the energy requirement for maintenance of Thai native cattle is lower than that reported by DiCostanzo et al.(1991) (655 KJ/kgBW$^{0.75}$/d), Reid et al.(1991) (580 KJ/kgBW$^{0.75}$/d) and Unsworth et al.(1991) (670 KJ/kgBW$^{0.75}$/d). However, the energy requirement for maintenance of Thai native cattle is lower than beef cattle in temperate zone by recommendation of ARC (1980) (527 KJ/kgBW$^{0.75}$/d) and NRC (1976) (540 KJ/kgBW$^{0.75}$/d). The energy requirement for maintenance across all types is shown in Table 2.2.

Table 2.2 Database of the metabolizable energy requirement for maintenance (ME_m) of cattleof various types

Reference	No of animal	Cattle	Method	ME_m
ARC (1980)		Beef		527
Kearl (1982)		Beef		493
NRC (1976)		Beef		540
Birkelo et al. (1991)	8	*Bos taurus*	IC; FHP/k_m	496
Birkelo et al. (2004)	45	Dairy cattle	IC; ER ra MEI	570
Chaokaur et al. (2007)	19	*Bos indicus*	ICH; ER ra MEI	497
Derno et al. (2005)	8	*Bos taurus*	IC; HP ra MEI	416
DiCostanzo et al. (1990)	28	*Bos taurus*	D_2O; ER ra MEI	655.6
DiCostanzo et al. (1991)	16	*Bos taurus*	D_2O; ER ra MEI	655.35
Ferrell and Jenkins (1998a)	70	Beef	CS; ER, HP ra MEI	495-529
Ferrell and Jenkins (1998b)	8-16	Beef crossbred	CS; HP, ER ra MEI	249-501
Hotovy et al. (1991)	4-8	Beef crossbred	IC; HP ra MEI	440-464
Kawashima et al. (2000)	20-44	*Bos indicus*	ICM; ER ra MEI	245-377
Liang and Young (1995)	8	*Bos indicus*	TOH; ER ra MEI	335
Montano-Bermudez et al.(1990)	76-494	Beef crossbred	FT; MEI ra BW	498-650
Odai et al. (2005)	20	Dairy cattle	ICM; ER ra MEI	409
Reid et al. (1991)	7-13	*Bos taurus*	CS; ER ra MEI	580-705
Reynolds and Tyrrell (2000)	34	*Bos taurus*	IC; ER ra MEI	503
Solis et al. (1988)	4	Beef	FT, BWC, ER ra MEI	383-636
Tedeschi et al. (2002)	24-48	*Bos taurus*	CS; ER, HP ra MEI	469-498
Unsworth et al. (1991)	12	*Bos taurus*	IC, CS; ER ra MEI	670-687
Warrington et al. (1988)	46	*Bos taurus*	D_2O; ER ra MEI	661-707

Source: Adapted from Chaokaur and Sommart (2008)

Note: ER, energy retention; HP, heat production; TEG, tissue energy gain; FHP, fasting heat production; BWC, body weight change; IC, indirect calorimetry; ICH, indirect calorimetry head cage; ICM, indirect calorimetry mask; CS, comparative slaughter; TOH, tritiated water (TOH) dilution;; FT, feeding trial; ra, regressed against.

2.4.3 Energy requirement for growth of beef cattle

The definition of energy requirement for growth is the energy which an animal requires for tissue to be deposited, that is a function of the proportion of fat and protein in empty body tissue gain (Garrette, 1959; CSIRO, 1990; NRC, 2000; Pond et al., 2005). ARC (1980) and Ferrrell and Oltjen (2008) stated that energy requirement for growth generally means that the energy required must not only maintain weight and body regulation, but it is also adequate to gain in body weight. The normal growth curve or growth pattern of animals can be used to determine the energy requirement for growth (Flatt and Moe, 1969; McDonald et al., 2002).

In Thailand, the data for evaluation of energy requirement and energetic efficiency for growth is very limited and is one of the main problems in developing feeding standards in this country. Chaokaur et al. (2009), reported that metabolizable energy requirement for growth 1 g/kgBW$^{0.75}$/d of Brahman cattle was 22.67 KJ/d and Nitipot et al. (2009) reported that metabolizable energy requirement for growth 1 g/kgBW$^{0.75}$/d of Thai native cattle in Thailand was 31.37 KJ/d. Moreover, Tangjitwattanachai et al. (2008) shows that the efficiency of metabolizable energy utilization for growth ($k_{g,}$) by using meta-analysis, that the energetic efficiency of *Bos indicus* cattle was higher than that of *Bos taurus* by approximately 11.76 %. These results are similar to those for Brahman cattle reported by Ferrell and Jenkins (1998) and Nellore cattle as reported by Tedeschi et al. (2002) and Chizzotti et al. (2008). However, this recommendation was developed from a small database and this is highly variable. Therefore, a lot more elucidation is required to clarify the energetic efficiency and the nutrient requirements for growth of growing beef cattle. More energy feeding trials and energy balance trials are needed to evaluate energetic efficiency and energy requirement for growth in growing and fattening beef cattle on different feeds and feeding management under humid tropical conditions in Thailand.

2.4.4 Nutritional control of growth

Growth can be measured in terms of body parts, organs and tissues. Nutrition is one primary input related to the growth of chemical components (water, protein, fat and ash) of the body, as determined the nutrient requirements. Fat and protein mass in the body are mostly factors which are related to body energy retention (Freetly et al., 2008; Schroeder and Titgemeyer, 2008). To date, most studies with beef cattle quantifying tissue accretion have examined the quantities of water, fat, protein and ash in empty body weight or carcass (Owen et al., 1995). The fat deposition and protein deposition in empty body were associated with the variation of weight (NRC, 2000) hormonal status (Lindsey et al., 1993; Owen et al., 1995) and nutritional control (McDonald et al., 2002; Pond et al., 2005).

As the energy intake above maintenance increases, protein synthesis rate becomes the first factor limiting, and excess energy is deposited as fat; decreasing the body proportions of protein, ash, and water, which are deposited in nearly constant rations to each other for a particular age of animal (Garrette, 1987; Murray et al., 1988). This statement matches the reports of Koch et al. (1979), who found that fat deposition increased with increasing age. Although the rate of fat deposition was constant, the percentage of fat in the animal matures and other structures stop growing. Perry et al. (1991) and Rumsey et al. (1992), indicated that protein mass had increased with age, fat mass had increased with age or weight, but fat mass accumulated during the background period varied with energy intake.

Allison (1975) and Berg and Butterfield (1976) implied that fat deposition was a linear function, which occurs in growing animals only after the caloric intake exceeds the requirement for maintenance and protein deposition. On the other hand, the relationship between fat and protein mass to empty body weight for feedlot cattle are shown in general to be curvilinear (Zinn and DePeter, 1991; Owen et al., 1995). Most other reports indicate that the mass of fat increases quadratically with weight whereas protein mass increases more linearly (Preston et al., 1973; Perry et al. (1991); Comerford et al., 1992; Ferrell and Jenkins, 1994). However, these do not agree with the result of Ingle et al. (1972) and Pathoven et al. (1975), who found that the rate of fatty acid synthesis per unit weight of adipose tissue decreased with increasing cattle weight and lypogenic capacity per unit weight of cytosol protein decreased linearly with increasing animal weight. Moreover, the presence of a quadratic pattern in fat accretion may support the validity of the concept that rate of fat accretion is more rapid for faster gaining cattle fed *ad libitum* access to feed. Accordingly, these results probably reflect differences in genotype in addition to average daily gain assume that protein accretion is weight dependent and larger mature weight, deposition more protein per unit of fat deposition (Perry et al., 1991; Rumsey et al., 1992; Owen et al., 1995). The efficiency of energy utilization for protein and fat synthesis in cattle are within the ranges of 10-40% and 40-80% (Garrette and Johnson, 1983), 45% and 85% (Kirchgessner et al., 1976), 34% and 69% (Reid et al., 1980). These results confirm the hypothesis that protein deposition in growing animals is energetically less efficient than fat deposition (Graham, 1980; Van Es, 1980; Old and Garrette, 1987; Gill et al., 1993). However, there are many factors affecting the rate of tissue accretion (sex, mature size, cell number (DNA) and nutrient intake)(Murray et al., 1988; Owen et al., 1995; Ferrell and Jenkins, 1994) and there is still very limited in formation on tissue accumulation and energetic efficiency of nutrient deposition in the animal body. Thus, the establishment of body growth research and nutrient accretion research are critical requirements to clarify the nutrient requirement and developed feeding standards for Thailand.

2.5 Factors affecting energy requirements

The maintenance energy requirement is shown to vary with many factors such as sex, stage of production, seasonal difference, nutritional environment, surrounding condition and physiological stage (ARC; 1980; Kearl, 1982; NRC, 2000; WTSR, 2008). A number of the most important are described;

2.5.1 Genetic potential or breed

NRC (2000) indicate that maintenance energy requirements of *Bos indicus* cattle are about 10% less than British cattle. Likewise, the other researchers (Ferrell and Jenkins, 1998; Sainz et al., 2005; Chizzotti et al., 2007; Tangjitwattanachai et al., 2008) reported that *Bos indicus* have a lower maintenance requirement than *Bos taurus*. However, all adult and growing cattle show a positive relationship between maintenance requirement and genetic potential for efficiency. Selection of animals well adapted to the different environments has the main propose of utilizing feed resources with higher efficiency (NRC, 2000; Zinn et al., 2008).

2.5.2 Age

A few studies indicate that age of the animal affects its energy requirement (Freetly et al., 2002; Chizzotti et al., 2008; Zinn et al., 2008). The maintenance requirement per unit of body size declines as cattle age increases (Blaxter, 1967; ARC, 1980). Young cattle are essentially ruminant, so that part of the effects of age on energy utilization is the switch to high fiber diets (Sanz Sampelayo et al., 2003). This change as well as the energy losses caused by fermentation and the increasing proportion of fat in body tissue, tends to increase the energy requirements per unit of weight increment (Flatt and Moe, 1969). NRC (2000) reported that the efficiency of utilization of a ration by growing heifers was greater for growth than for fattening. This decrease should lead to a lower maintenance requirement for adult animals, and thus leave a greater proportion of the ration for productive purposes (Flatt and Moe, 1969; Zinn et al., 2008).

2.5.3 Sex

The ARC (1980) and AAC (1990) similarly concluded the basal metabolism of castrated males and heifers was similar. Also, it has been shown that maintenance requirements of bulls are 15% higher than that of steers or heifers of the same genotype (NRC, 2000). Previous studies indicate that sex of the animal has an influence on energy requirement (Chizzotti et al., 2007b, 2008; Zinn et al., 2008).

2.5.4 Physical activity

Using a small research, AAC (1990) estimated the increase in maintenance energy requirements of grazing compared to corral cattle to be 10 to 20% in best grazing conditions and about 50% for cattle on extensive holdings. Therefore, several studies indicate that physical activity of the animal has an influence on energy requirement (Ortigues et al., 1993; Lachica and Aguilera, 2005; Brosh et al., 2006; Van Knegsel et al., 2007; Suzuki et al., 2008a). The ARC (1980) estimate the requirements for standing at approximately 10 KJ/kgBW/d. Eating and ruminating requirements depend on the type of diet (large or long particles or ground and pellet, concentrate or roughage, solid or liquid) (Ørskov and Ryle, 1998). Blaxter (1967) suggested that the requirements for walking are about 2 J/kgBW/d. These data indicate that when the physical activity changes the maintenance requirement changes also.

2.5.5 Environmental temperature

Temperature is one factor with several effects on energy requirements, which depends on the relative humidity (RH), wind velocity, season and length of hair coat of the animal (Kurihara, 1991; Fox and Tylutki, 1998; Mader, 2003; Terada and Shioya, 2004). Heat production and heat dissipation are adjusted to maintain a constant body temperature. Heat dissipation is primarily regulation of the body temperature (Blaxter, 1967; ARC, 1980). When ambient temperature increases above thermo neutral zone, the energy requirements for maintenance increase because of increased tissue metabolic rate and increased heat dissipation. When, ambient temperature is lower than the upper critical temperature, the energy requirements for maintenance also increase and animal metabolism increases to supply adequate heat to maintain body temperature (Flatt and Moe, 1969; Ø rskov and Ryle, 1998). Heat stress and cold stress occur, when the ambient temperature is higher or lower than upper critical temperature. The upper critical temperature varies with the rate of heat production in thermo neutral conditions and the animal's ability to dissipate or conserve heat (Van Soest, 1994; Ørskov and Ryle, 1998).

2.5.6 Hormonal status

The relations of hormones and energy metabolism show that the hormones regulate glucose supply and utilization (Flatt and Moe, 1969). When the hormones are rising, metabolic activity will increase the need for energy supply (Weekes, 1991; Pittroff et al., 2006). Tschop et al. (2000) and Patel et al. (2006) revealed that growth hormone and thyroid hormone have been reported to alter energy metabolism and fat accretion. Similarly, Wertz-Lutz et al. (2008) indicated that ghrelin hormone can stimulate and induce glucose uptake by adipocyte in tissue depots, which results in a different metabolic state of cattle.

2.5.7 Level of nutrition

Protein and fat deposition depend on the level of energy intake (Lofgreen and Garrett, 1968). Some studies indicate that feeding level has an influence on energy requirement (Kirkland et al., 2002; Liu et al., 2005; Mahgoub et al., 2005; Castro Bulle et al., 2007; Freetly et al., 2008). There is an increase in energy retention with increasing protein and energy intake. In the general, it is believed that an increase in fat and protein deposition occurs with increasing energy intake (Chowdhury and Ørskov, 1997; Schroeder and Titgemeyer, 2008).