JBT

Examensarbete 9
Thesis
Alnarp 2002

Estimation of production losses and measures to reduce thermal stress in dairy production under tropical conditions - results of a field investigation

Beräkning av produktionsförluster och metoder för att minska värmestress vid mjölkproduktion i tropiskt klimat – resultat av en fältundersökning

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Examensarbete för agronomexamen

Keywords:

dairy production, heat stress, tropical conditions, respiration rate, coat temperature, relief measures

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Preface

Many countries in Asia has increased their milk consumption during the last years. That has contributed to the governments wishes to increase the production of milk. There are different ways to achieve a higher milk production, one is to import high lactating breeds like Holstein and Jersey. The problem with that is the climate that effect the higher milking breeds in a bad way.

Heat stress in dairy cows is common in hot climate, but in these tropical countries the effect is even worse. The humidity and heat together will lead to make it difficult for the animals to dissipate heat.

The general objective of this thesis was to search for and evaluate cooling or heat stress relief systems for dairy cows in tropical climate. The practical study was made on farms in Vietnam and Malaysia during September 2002. The theoretical milk production loss was calculated and an evaluation of the different roof materials was made. The work was carried out by Malin Qvarnström, with professor Krister Sällvik as supervisor and also examinator. Opponent on the presentation was professor Hans Wiktorsson.

I would like to thank Mr Gert Danneker at DeLaval that helped me with the idea and formulation together with my supervisor professor Krister Sällvik at JBT in Alnarp. Gert also arranged the trip to Vietnam and Malaysia.

Also thanks to Agr. Eng. Bengt-Göran Mårtensson, DeLaval, for all the support, assistance and valuable suggestions with my work in Vietnam. The measurements in Malaysia were arranged with the help from Mr Ahmad Ridzuan Zakaria, Teknoniaga. The measurements would not have been possible without the instruments borrowed from JTI.

I am especially indebted to:

Agr. Eng. Lennart Bengtsson for always being there to help.

My parents Christina and Göran Qvarnström for the help with the English spelling and grammar and comments on the content.

My sister Johanna Qvarnström for the help with the scientifically way of expressing and formulation.

My fiancé Arg. Eng. Fredrik Andersson and my friend and classmate Maria Hilltorp for keeping up with me and always supporting me during the bad days.

Finally also a big thank to my friends, Linn Umeland, Cecilia Strömberg and Peder Schiöler for their comments and help.

Ultuna Dec 2002

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Sammanfattning

Mjölkkonsumtionen i Asien har ökat i rask takt de senaste åren. Den ökade konsumtionen leder till att produktionen måste ökas, bland annat genom att använda högmjölkande raser så som Holstein och Jersey. Dessa raser plus den höga produktionen ger problem med värmestress. För att behålla en hög produktion behöver man någon slags kylning av korna.

Värmestress är väl dokumenterat i både Sydamerika och södra delen av USA. i Asien kan det vara ett ännu större problem i och med att de har en konstant temperatur året runt.

Den här studien syftar till att göra en bedömning av produktionsbortfallet och på vilka åtgärder som kan användas för att minska effekten av värmestress i tropiska klimat.

Examensarbetet är indelat i två delar; en litteraturstudie och en praktisk studie. Den praktiska delen gjordes på fem gårdar i Vietnam och två i Malaysia under september månad 2002. På tre av gårdarna gjordes mätningar två olika dagar men på grund av tidsbrist gjordes bara en dags mätning på de andra gårdarna.

Data som insamlades var temperatur inne, ute, inkommande solstrålningsenergi, luftfuktighet inne samt yttemperatur på takets insida. På de tre djur som vid mättillfället mjölkade mest mättes andningsfrekvens och yttemperatur på kons päls.

Vid de tillfällen solen sken var korna värmestressade, det visade både THI (temperatur och fuktighets index) och andningsfrekvensen. Teoretiskt minskade mjölkproduktionen på grund av värmestressen i genomsnitt 7 kg mjölk/dag och ko.

Innan mjölkning duschades korna för att få bort smuts och detta minskade även värmestressen på korna. På en av gårdarna i studien spolade man vatten på taket för att få ner värmen i stallet. Genom denna åtgärd minskade kornas andningsfrekvens/min jämfört med den dag då de inte spolade vatten på taken. En annan av gårdarna hade fläktar installerade i taket. Tyvärr kunde detta inte utvärderas eftersom det regnade den dagen mätningarna gjordes.

Några enkla sätt att minska värmestressen på korna på de gårdar som besöktes skulle vara att se till att korna alltid kan stå i skugga samt att ha vatten tillgängligt hela dygnet. Andra sätt kan vara att måla taket vitt på översidan och svart på undersidan, installera ”tropikfläktar”, duscha korna oftare, använda zonkylning (då man riktar en kall luftstråle mot en del av kroppen t.ex. nacke eller huvud och får ökad avkylning) under de varmaste timmarna på dagen eller använda tunnelventilation (ökad lufthastighet i hela stallet med hjälp av fläktar).

Tidigare försök visar att evaporativ kylning med duschar och fläktar ger en ökning av mjölkproduktion och foder intag och minskning av andnings frekvens och kroppstemperatur.

Mekanisk kylning med AC ger kanske den bästa klimatstyrningen men energiförbrukningen är hög med runt 2500 W/ko. Det gör att mekanisk kylning bara kan komma i fråga för hög-producerande kor i varmt och fuktigt klimat.

Vid nybyggnation bör man tänka på att försöka utnyttja den naturliga vinden så mycket som det går genom att placera byggnaden lämpligt i landskapet. Man bör

även välja material i tak och eventuella väggar som ger en minskad värmeinstrålning på grund av solinstrålning, samt utnyttja proportionerna på byggnaden så att man får en bra genomluftning och tillräcklig skugga. Den lägsta höjden på tak är enligt rekommendationer 3,6 m eller 4,3 m ifall stallet är bredare än 12,2 m för att försäkra sig om en tillräcklig lufthastighet i mitten på byggnaden. Takmaterial som har en isolerande förmåga ger en lägre instrålningsvärme och är därmed att föredra i tropiska klimat.

Summary

The milk consumption in Asia has increased during the last years. To improve the milk production high yield breeds like Holstein and Jersey are introduced however they are more sensible to the hot and humid climate compared to local breeds. To keep their milk production at a high level some sort of cooling must be used.

Heat stress in dairy cows is a well-documented problem in South America and the southern part of the USA. But in parts of Asia the problem with heat stress is even worse because of the constant heat.

This study aims to search for and evaluate different cooling or heat stress relief system in hot and humid climate.

The thesis is divided in two parts, a literature study and a practical study. In the practical study five farms in Vietnam and two farms in Malaysia were studied during September 2002. At three of the five farms the measurements were performed on two different days but due to the lack of time the other farms were studied only one day.

Data collected were out and inside air temperature, incoming solar radiation towards the barn, the relative humidity inside and the surface temperature of the inside of the roof. On the three highest yielding cows the temperature of the hair coat surface and respiration rate were measured.

When the sun was shining both respiration rate and THI (Temperature and Humidity Index) showed that the cows in these farms were heat stressed. The theoretical calculated milk production loss on these farms was in average about 7 kg milk/day and cow.

Before the milking the farmers washed the cows from dirt, that gave the effect of decreasing the heat stress. One farm sprinkled the roof to get the building cooler. This showed to have a positive impact by decreasing the breathing rate compared to a day when the sprinklers were not in use. Another farm had fans or vertical air circulation installed in the ceiling. But because of rainy weather the effect by these fans could not be evaluated.

To avoid or reduce heat stress and by that increase milk production on these farms, the farmers should make sure that the cows are always able to stand in the shade and that water is always available. Painting the roof white on the upper side and black on the under side, installing air circulation fans, showering the cows more often, using zone cooling (directing a jet of mechanically cooled air onto a part of the body for example neck or head to get a better heat dissipation), during the hottest time of the day or using tunnel ventilation (getting a sufficient air velocity across the building by using fans) are other options to decrease heat stress.

Earlier made field studies shows that evaporative cooling with showers and fans will give an increase in milk production and feed intake and a decrease in respiration rate and body temperature.

Mechanical cooling with AC will probably give the best climate for the cows but the energy consumption is high with 2500 W/cow. Therefore the mechanical cooling could only be feasible to high-producing cows in hot humid climate.

New buildings should be optimal constructed to utilise the natural wind for convective cooling of the cows. Other measures could be using materials in roof and possible walls that will decrease the effect of solar radiation and also use proportions of the building that will optimise good shade and ventilation. The minimum height of the roofs is recommended to be 3.6 m or 4.3 m if wider than 12.2 m to get sufficient air movement in the centre of the shade. Roof material with insulating capability is the best materials to be used in tropical climate.

Introduction

An increased consumption of milk products in Asia has added to the interest in systems for intensive milk production in tropical climates. The earlier used extensive/tropical/grazing models are giving poor and costly milk. Using breeds like Holstein and Jersey could solve higher milk yield. These breeds require some type of cooling system to avoid heat stress under the hot and humid conditions that parts of Asia have.

The climate in Vietnam and Malaysia and the fact that there is no tradition in dairy production makes it hard to get a market started to invest in dairy farming. If the problems with the heat stress could be solved it would be much easier to continue with the other production issues such as foodstuff, equipment and how to understand the need of the cows. A reduced heat stress can lower or eliminate losses in milk yield, losses in fertility and increase feed intake. The money earned by increased milk production has to cover the money spent in a cooling system for the cows, to get economy in the system. A domestic milk production will help the national economy in these countries.

This thesis will try to evaluate the most common and the thinkable cooling systems used in tropical climate by a literature review and a practical study. Problems with and effects of heat stress and cooling systems are summarised and the desirable climate for the cow is discussed.

In a practical study in Vietnam and Malaysia heat stress of lactating dairy cows was measured. Significant parameters such as breathing rate, dry bulb temperature, wet bulb temperature, air velocity, humidity and the temperature of the skin of the animal, the heat stress could be evaluated using well-known theory.

Objective

The main objective of this study was to search for and evaluate different cooling systems to decrease the heat stress at dairy cows in hot and humid climate. That will provide fundamental information for advisers and designers of dairy production facilities in these countries.

Literature review

To get a good understanding for the subject and different views of the problem it has been necessary to search for information from a wide range of sources. Experiments on heat stress on dairy cows started in the beginning of 1940's at the University of Missouri. Since then the problem with heat stress has got more and more attention. Although the problems are more severe in the parts near the equator, most research has been made in the south of the USA.

Heat balance

Animals like man need food and energy just to supply their maintenance (breathing, blood circulation, muscle tension and renewal of tissues). All this transformation of energy produces heat, which has to be dissipated. In the process of transforming energy to products, that is milk, even more energy is used and therefore more heat must be dissipated. Stress caused by heat has the biggest impact on the highest producing cow because of the total heat-load (heat produced inside the cow + heat from the environment if warmer that body temperature). The warmer environment and the higher production the more problem with heat balance.

The heat must be continuously dissipated or else the body temperature might rise above normal level for the animal, which could be fatal for warm-blooded animals.

When the environmental temperature is below body temperature, the heat will dissipate from the surface area of the body by radiation and convection. Radiation is sending out heat to surrounding surfaces and convection is heating air near the skin that is replaced with cooler air, which in turn get heated and moved away. If the cow is lying down on a cool floor the heat will be dispatched by conduction. Radiation, convection and conduction are so called sensible heat (Figure 1)

Other ways of losing heat is evaporation, (sweating and breathing) (Figure 2), also called latent heat. When the cow is panting the inhaled air is cold and will be warmed up and exhaled and thereby remove heat from the body. In warm environments the heat is lost by vaporisation of moisture in the lungs, like sweating in the lungs (Stowell, 2000). Latent heat dissipation is mostly depending on reduced possibilities of sensible heat dissipation Figure 3. Vaporization is also dependent on surface area, differences in vapour pressure between surface and surrounding air, rate of air movement and the extent of respiratory activity (Brody, 1948). A large animal is more sensible to rising environmental temperature than a thinner and smaller animal because of the relation between volume and surface area (Ragsdale et al., 1949). By diffusion and sweat the water is vaporised from the skin of the cow. A cow has 1800 sweat glands per cm^2, therefore the sweating is an important way of losing heat (Sällvik, 2001).

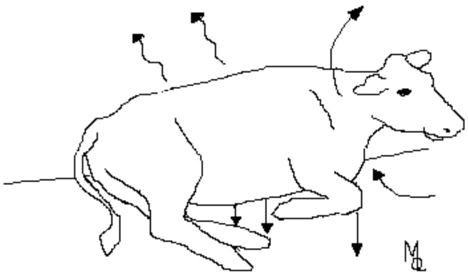

Figure 1. Radiation, convection and conduction; sensible heat

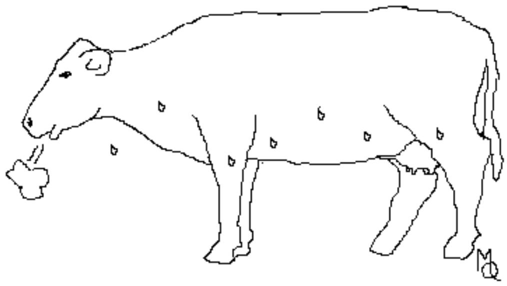

Figure 2. Sweating and breathing; latent heat.

The total heat production is the summation of the latent and sensible heat loss (Figure 3). At the lower critical temperature the sensible heat loss is up to 80 % but as the temperature rises the latent heat loss will get more and more importance and at a temperature around 40-41 ºC the latent heat will be 100 % (Ehrlemark, 1991). If the temperature is lower than the critical temperature, the animal will need to eat more to get more energy for keeping the body temperature at the normal 38 ºC and if the food energy is not enough, the fat reserves will be used. Small natural changes of the body temperature can occur depending on hard work, metabolism, physiological changes (for example oestrus) or stress (Sällvik, 2001).

Heat stress arises from any combination of environmental conditions that cause the effective temperature of the environment to be higher than the animal's thermoneutral (or comfort) zone. Factors that contribute to increase environment temperature are air temperature, relative humidity, air movement and radiation from the sun (Buffington et al., 1981).

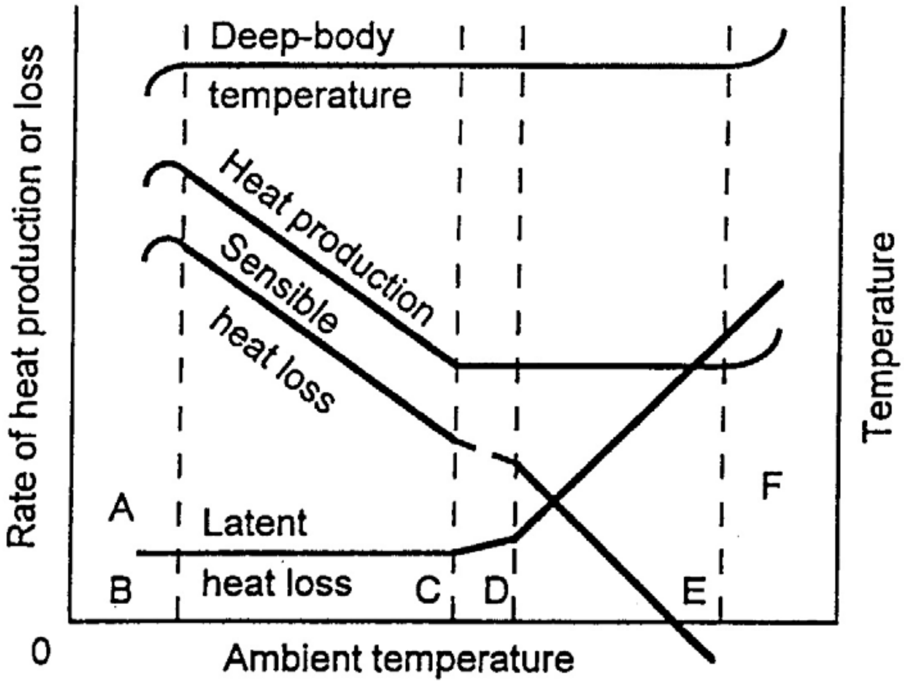

Figure 3. Diagram showing the relationships between the deep-body-temperature, total, sensible and latent heat loss in a homoeothermic animal due to the environmental temperature. A: zone of hypothermia; B: temperature at maximum metabolism and beginning hypothermia; C: lower critical temperature; D: temperature of marked increase in latent heat loss; E: temperature of beginning hyperthermia; F: zone of hyperthermia, CD: thermoneutral zone or comfort zone; CE: zone of minimal metabolism; BE: thermoregulatory range (Mount, 1973).

Effect of heat stress on dairy cows

When temperature increases over a certain temperature, the rate of vaporization from the body increases. The cow respiratory rate will rise and the cow will also sweat more. The cow will loose water and that she therefor needs to drink more, and the lactating cow needs to drink more water than when dry. The cow will adjust the water intake as long as she has got access to water all the time (Thompson et al., 1949).

Heat stress will lead to a rising deep body temperature and skin temperature and the skin temperature is continuously rising with the ambient temperature. To cool, the blood will be led through the blood vessels near the skin and by that lead heat from the core to the skin surface. This is special for humid climate, in dry air much higher temperatures are tolerated. Sweating is limited in time and rate, for example; a human cannot sweat more than 0,3 g/s (1L/h) in a normal environment, which gives a cooling effect of maximum 350 W/m^2. Another problem could be that the blood pressure will fall and that will lead to a lot of blood in the extremities and little blood to the brain. Depletion of salt and water leads to exhaustion and may give heat cramps and worse stroke (ASHRAE, 2001).

The fat percentage in the milk will rise from normal values when temperature rises above 30 ºC (85 ºF) (Ragsdale et al., 1949) and decreased quality of milk may have negative impact on the cheesemaking properties of the milk (Calamari and Mariani, 1998). Research has shown that cows in hot environment have higher requirements than normally recommended of certain minerals. That might be an impact of the amount of feed intake and the feeding strategies (Baksh, 2000).

Heat stress is a major contributing factor in low fertility on lactating dairy cows in hot climate. The progesterone secretion is lowered, oocyte quality and embryo development is becoming poorer and there is an increased embryo mortality. It might even lead to termination of pregnancy. But there are more than just the immediate effects; heat stress may also have a delayed effect. For example, suppressed production of follicular steroids, low quality of oocyte, weakened embryo development and changed follicular dynamics (Wolfenson et al., 2000). Also the reduced activity during estrus, because of the hot climate, will make it harder to detect when the cow is on heat (Steevens. 1997). The breeding efficiency can increase with approximately 100 % by using a cooling system involving shade and artificially induced air, in a hot climate (> 27,5 ºC) (ASHRAE, 2001). Conception rate, for example in the state of Sao Paolo in Brasil the inseminations per pregnancy are sometimes three folded during summer compared with winter. (Sällvik. pers.ref., 2002)

Heat stress may result in greater affect of diseases because of a weaker immune system (Bertoni, 1998).

The metabolic heat regulation is defined as a change in heat production. When the temperature is lowered, the body will use a greater quantity of the food to produce heat and there will be less energy left for the milk production. If the ambient temperature rises the cow will not be interested in eating as much food because that will lead to more heat production within the animal. Therefore the feeding intensity is used in the formula for estimating the heat production of one cow in eq. (1) (Swedish Standard, 1992).

$$P_{tot} = 5{,}6m^{0{,}75} + Y_1 + 1{,}6\times10^{-5p^3} \quad (1)$$

P_{tot} =The animal's total heat dissipation, W

m = The animal's weight, kg

Y_1 = Production of milk, kg/day

p= Days of pregnancy, day

Methods to reduce heat stress

To reduce heat stress in warm climate handling of the animals should be kept at a minimum. The animals should be provided with shade and fresh water; especially important is to provide water near the feeding area. Daily water consumption can vary between 60-150 litres per cow. Dairy cows need approximately 3-4 litres of water per litres milk produced (Steevens, 1997).

Shade can be natural (trees) or artificial. The floor should be larger than the area of the roof so that the cow can move to avoid direct sun. The sun and thereby the shade will vary over the season and the time of the day and the shade will not always be under the structure (Bucklin et al. 1991). The minimum height of the roofs is recommended to be 3.6 m, or 4.3 m if wider than 12.2 m to assume sufficient air movement in the centre of the shade (Buffington et al., 1983). To get the most effective result, metal roofs should be painted white on the upper side of the roof and painted black on the under side (Bond et al. 1961) and be insulated. Insulation will reduce the radiated heat load on the cows but can give problems with for example birds and other animals that can damage the material (Buffington et al., 1983). A sunshade is the most cost-effective way of reducing solar radiation stress. The shade will decrease the radiation from the sun and thereby the heat loads on the animal, but the humidity and temperature of the air will still be the same (Strickland et al., 1989).

The air movement is an important factor in decreasing heat stress. The air movement, caused naturally and mechanically, will help to improve heat dissipation by convection and sweating. It is recommended to have a system that can give an air change in the building once every minute (Bucklin et al., 1988). Mechanical ventilation is very effective in providing air movement, but it can be expensive and often needs to be combined with other methods (Bucklin et al., 1991).

Planing and awareness of the risk of heat stress can solve most of these methods and heat load can be decreased.

Cooling systems

Cooling is not as common as heating but can give an economical benefit in hot climates. In places were the climate is both warm and humid it is also important to know how the cooling system is functioning to get an adequate result.

Sprinklers and fan

One of the most commonly used system to reduce heat stress is sprinkler and fan cooling, the sprinklers create droplets that wet the skin of the cow and with the fans they create an evaporative cooling (Turner et al., 1993). If the droplets are very small it is called fog or mist system. Those systems are not recommended in humid climates. The fog can create a “steam bath” effect instead of cooling the cow (Bucklin et al., 1991). These evaporative systems are typically installed in the feeding area of a free stall, beneath an outside shaded feed bunk or in the holding pen of the milking centre. If installed in the bedding or resting area an increased mastitis rate could be the result (Chastain, 1994).

The minimum controls for this cooling system is a thermostat and an adjustable timer. The thermostat should activate the cooling system at 25 ºC. Sprinklers will have a period of 1-3 minutes of spraying and 4.5-15 minutes off. Fans will be set to operate continuously when the system is activated. On the basis of results of field studies in Florida (Strickland et al., 1989), Missouri (Igono et al., 1987), and Kentucky (Turner et al., 1992), expected benefits of evaporative cooling are increased feed intake (7.8 %), increased milk production (2.5 kg/day), decreased body temperature (0.2-0.5 ºC) and a reduction in breathing rate (29 %).

In a humid climate the velocities are recommended to be 2.9 to 4.0 m/s depending on airflow direction (Chastain, 1994). A drawback with the evaporative cooling is however the large amount of water used (Turner et al., 1992). It is important that the water is clean to avoid spreading of diseases.

Showers

Cooling animals directly with showers, using conduction and evaporation is another way of dealing with heat stress by using water. A twenty seconds short shower will cool as long as it takes the cow to get dry (about ten minutes) and requires a modest amount of water. The watering system can be regulated by a timer to shower a whole area every 90-120 minutes, or if a large area, by a sensor trigged by the animal itself (Chiappini et al., 1992). A problem with this system is the great quantities of water that leads to wet floors and the increased amount of liquid waste and slurry (Frazzi, 2002). The water used should be clean so that infections are not spread.

Cooling pads

Adiabatic or evaporative cooling through water evaporation in the incoming airflow is an economical method resulting in a temperature reduction of 8 to 10 ºC. But it also means an increased relative humidity, up to 90 % (Chiappini et al., 1992). This system uses pads and pumps to poor water though the pads (Kelly and Bond, 1958). There could however be a problem with salt content in the water. One should also consider that the cooled air must have a short way through the building to avoid high temperature and high humidity. To get the most out of an evaporative cooling it should be installed in an adequate insulated building (Chiappini et al., 1992). This system is often used in broiler production in Brazil and in farrowing nursery buildings in Mid West USA (Sällvik. pers.ref., 2002).

Pools

In the tropical parts of the United States the use of cooling ponds is common. In 1988 30 % of all dairies in Florida used some cooling ponds during summer. Man-made pools with fresh water flowing through are shown to give no increase in mastitis (Bray and Shearer, 1988).

Ground cooling

Techniques not so commonly used are for example cooling the ventilation air by heat exchange with colder environment, usually 1,5 to 2,5 m in the ground. The relative humidity of incoming air is increased due to the effect of the temperature reduction. The air will cool during the day, in the Mediterranean up to 12-15 ºC, but during the night the air will actually get warmer if the night temperature drops under the earth temperature. Basically the ground cooling will eliminate the extreme peaks in temperature. The incoming air temperature is very close to the monthly average temperature (Chiappini et al., 1992). In Vietnam and Malaysia temperatures are quite unchanged over the year and over day and night. That means that cooling systems using earth or rocks to cool the incoming air will not work as it is intended to.

Tunnel ventilation

Tunnel ventilation will give a slightly lower temperature indoor than if natural ventilation is used. Directing airflow toward the cow has been shown to increase the dissipated heat and thereby reducing the number of hours or days of heat stress. The most common system to install tunnel ventilation is axial-flow fans in one short end of the barn and then additional fans placed over the interior regions of the barn, all directioning fans towards the opposite end. The positive result of tunnel ventilation is that the cows get access to good airflow in the whole building; the disadvantage is the electricity consumption (Stowell et al., 2001).

Mechanical cooling

Mechanical cooling with refrigeration or heat pump is generally considered too costly in animal housing. This method can change temperature inside to considerable lower temperature compared to outside (Chiappini et al., 1992) but it needs a well insulated building to be of any interest. Also an insulated building with this system needs a close attention to air filtration, adequate ventilation and maintenance. Air conditioning of dairy housing is depending on the local design conditions and the individual situation of the cow, but approximately the energy needed is 2500 J/s (W) or more. The mechanical cooling could be feasible only to high-producing cows in hot humid areas (ASAE Standards, 2002).

Zone cooling

Inspired air or zone cooling applies a jet of cooled air onto the head and neck of the cow. The air may be cooled by evaporative cooling or by mechanical refrigeration. Because of the installation costs and lack of compatibility with housing systems this has not become a common cooling system (Bucklin et al., 1991). Air cooled by refrigeration to 15 °C, supplied at a rate of 0,7-0,85 m^3/min and cow has been showed to benefit milk production. Hahn et al (1965) provided the air through head enclosures in the experiment, therefor a kind of zone cooling.

Water on roof

If a wall or a roof is wet, energy and therefore heat will be used to evaporate the water. When water evaporate from the outside of a roof the energy used is taken from the sun energy and the energy outside in the air, very little energy is coming from the inside of the roof. That means that the radiate sun energy will be reduced (Nevander and Elmarsson, 1994).

Insulated buildings

If animals are housed in buildings, their sensible heat losses heat up the inside air. The houses in its turn lose heat by transmission through the walls, roof and floor and by ventilation. That means that the insulation and surface areas on the building is important for how much heat is transferred from the building. In cold climate, the buildings are well insulated to keep warmth inside. The ventilation will regulate the climate indoors and under certain cold outside conditions additional heat is needed to maintain the relative humidity below recommended level by ventilation and maintain inside temperature. An insulated building could be suitable in a warm climate too. But in that case the insulation should prevent the heat to get in.

Using mechanical cooling the house should be very good insulated and ventilation kept at a minimum to minimise electricity consumption.

Which temperature is feasible?

Some references (Yeck and Stewart, 1959) believe that milk production starts to drop at a temperature above 22 ºC, but other authors claim that milk production starts to drop at lower temperatures (Gebremedhin et al., 2001). Different breeds have different ideal environment temperature, e.g. temperature for Holstein cattle should not exceed 24 ºC while Jerseys are more tolerant and can except a temperature up to 27 ºC (Yeck and Stewart, 1959). They might all be right because temperature recommended for a certain animal is depending on the breed, size and production level as well as the humidity, as mentioned earlier. Figure 4 by Hahn (1983) shows the temperature range were the cows have optimal performance.

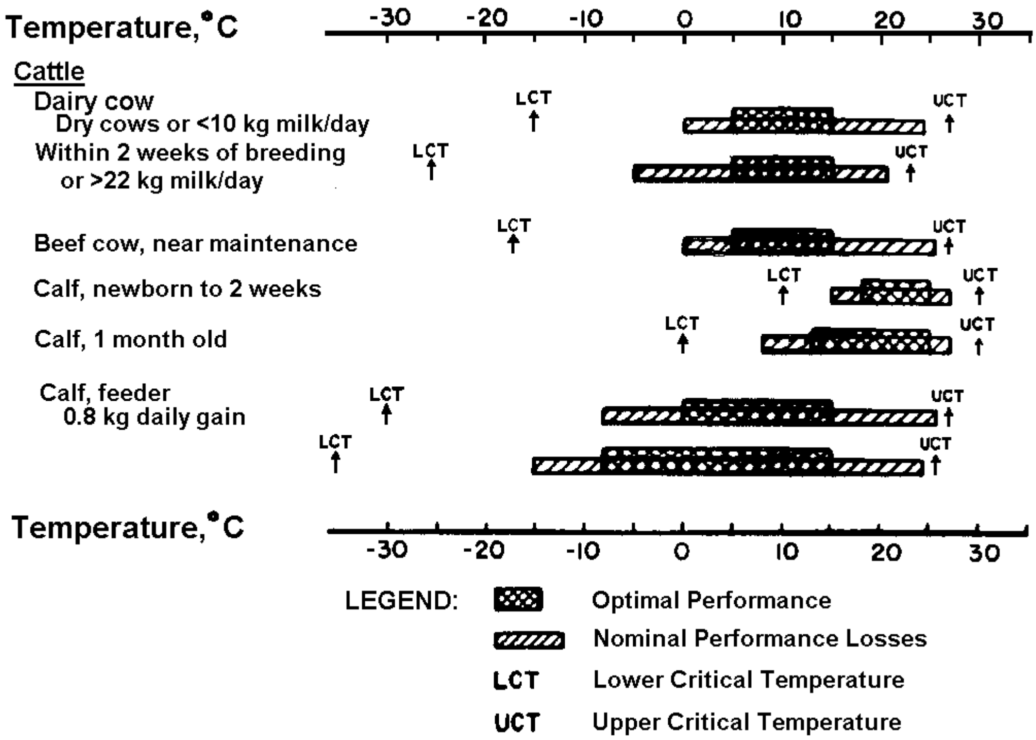

Figure 4. Temperature interval for the optimal production (Hahn, 1983)

UCT stands for upper critical temperature but is no longer used as an absolute definition. It could be explained as the point where the breathing frequency is raised. Also the lower critical temperature (LCT) is hard to define because of the individual conditions. Such as humidity and wind will affect the ambient temperature. A Heat Index (THI) shows the apparent temperature at certain air temperature due to relative humidity. In Figure 5 the general stress levels caused by temperature and relative humidity on dairy cattle are showed. For a more correct figure the air velocity should be included. Considering the mean temperature and humidity in Saigon and Singapore Table 2 and Table 3 respectively the worst scenario to reach would be severe stress according to Figure 5. A good rule is that the temperature in ºC added to the humidity in percent should be below 90 (CIGR, 1984).

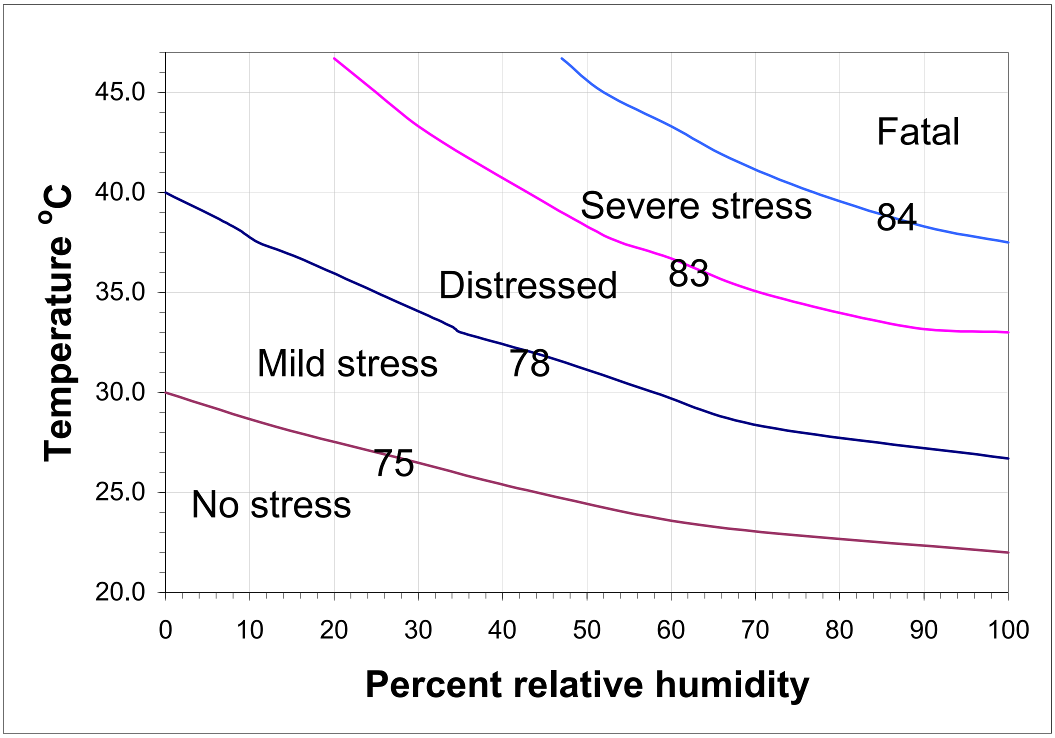

Figure 5 Relation between relative humidity and temperature to create THI-values and interpretation to heat stress levels (after Armstrong, 1994).

Dairy cattle experience heat stress at much lower temperatures compared to humans, they also have a comfort zone at much lower temperatures. The thermoneutral zone shift between cows, and it is often at temperatures that humans consider cool or cold (Gebremedhin and Wu, 2001). The thermoneutral zone depends on the cows heat production, eq (1), and also the possibility to dissipate heat.

At a certain temperature and with certain humidity the experience of the surrounding could still be various in different situations. If there is a wind blowing it will feel cooler, if the skin is wet it will feel even more cool. And also if the cow is a high producing cow or a low producing cow the experience will be different.

The effect of air movements is described in the eq (2).

$$P_c = 10 * \sqrt{v} * (t_a - t_s) * A \qquad (2)$$

P_c = energy loss by convection, W

v = Air velocity, m/s

t_a = temperature of the animal's surface, °C

t_s = temperature of the surrounding, °C

A = 80% of the animal's surface, m^2

But to get a good understanding a program like Anibal (Ehrlemark and Sällvik, 1996) should be used.

Evaluation of heat stress in dairy cows

There is no threshold value for the thermal impact where a certain cow is exposed to heat stress. There is a continuos change in physiological reactions. Compare Figure 5. It is known that the milk production decreases, that the body temperature might change, that the cow moves less, the feeding behaviour changes and breathing will be more frequent when it gets warmer. (Nienaber et al., 2002)

Many researches have shown that temperatures between 0-25 ºC have no effect on the milk production Figure 5. Hahn and McQuigg (1967) have set up an expression based on many different experiments to calculate the reduction of milk production, eq (3), as a function of hot climate based on the THI, eq (4), as daily mean value. THI is also used as the basis for the Livestock Weather Safety Index (LCT, 1970) and by the U.S. National weather service for advisories (USDC-ESSA, 1970) used in Figure 5, by Armstong.

$$M_{dec} = 1{,}075 - 1{,}7436NL + 0{,}02474NL * THI \quad (3)$$

$$THI = t_{db} + 0{,}36t_{dp} + 41{,}2 \quad (4)$$

M_{dec}= reduction in daily milk yield, kg/day

t_{db}= dry bulb temperature ºC

t_{dp}= dew point temperature ºC

NL= normal milk production kg/day

(Hahn and McQuigg, 1967).

Table 1 shows the milk decrease in kg/day in relation to the temperature and humidity using the expression in eq 3 by Hahn and McQuigg. The normal production in this case is 25 kg/day. The CIGR recommendation that the absolute sum of temperature + humidity should be 90 or lower is confirmed by this table.

Temp°C \ Humidity %	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
95	0	1,3	2,1	3,0	3,8	4,6	5,5	6,3	7,2	8,0	8,8	9,7	10,5	11,4	12,2
90	0	1,1	1,9	2,8	3,6	4,4	4,6	6,1	7,0	7,8	8,6	9,5	10,3	11,1	12,0
85	0	0,9	1,7	2,6	3,4	4,2	5,3	5,9	6,7	7,6	8,4	9,2	10,1	10,9	11,8
80	0	0	1,5	2,3	3,2	4,0	5,1	5,7	6,5	7,3	8,2	9,0	9,9	10,7	11,5
75	0	0	1,3	2,1	2,9	3,8	4,6	5,4	6,3	7,1	7,9	8,8	9,6	10,4	11,3
70	0	0	1,0	1,9	2,7	3,5	4,4	5,2	6,0	6,8	7,7	8,5	9,3	10,2	11,0
65	0	0	0	1,6	2,4	3,3	4,1	4,9	5,7	6,6	7,4	8,2	9,1	9,9	10,7

Table 1. Milk decrease (kg/day) in relation to temperature and relative humidity. Normal milk production 25 kg/day (based on Hahn and McQuigg, 1967).

The body temperature will increase with approximately 0.2 °C per °C above 25 °C in unshaded cattle (25≤t_{db}≤41 °C) (Nienaber. pers.ref., 2002).

A cow experiencing heat stress will behave in different ways, Young and Hall (1993) observed and listed the behaviours in increasing order. First the cow will align the body with the solar radiation, then she will seek shade, refuse to lie down, reduce feed intake, crowd at the water, splash water onto the body, then show agitation and restlessness, reduce rumination and group to find shade from other animals.

When temperature is increasing the feed intake of the animal is likely to decrease in meal size and increase in number of daily meals. It has been shown that the dynamics of eating affected by heat stress will change in 3-4 days of adjustment by the animal (Nienaber et al., 2001).

Other ways of measuring heat stress is by measuring the respiration rate. A cow normally have about 15-30 breaths/minute, a respiration rate of 80-90 breaths/minute are considered a clear indication of heat stress (Stowell, 2000). According to Hahn et al. (1997) and Gaughan et al. (2000) above 60 breaths/min the breathing rate will increase by 4.3 breath/minute per °C. A cow panting with open mouth and excessive drooling is an indication that the cow is failing to cope and may need special attention.

Materials and methods

In Vietnam and Malaysia the prerequisite is different from that in Florida and other places in the United States where most of the research considering heat stress has been made. For one thing, they have no tradition in dairy farming and the climate is different. The farmers visited had 4 –50 milking cows and cows were kept under roofs on concrete floor. Breeds on these farms were cross breed 73-75 % Frisian or Holstein-Frisian and local breed, except for one farm that had 100 % Jersey. The cows were milking in average 3000-5000 kg/lactation, and the lactation was 200-300 days (normal lactation is set to be 305 days). Before milking the cows were washed and thereby cooled. The food was in general Elephant grass (Pennistum purpureuum or Napier grass) cut in bigger bits. To get the best nutritional value the grass should be cut every 12-14 day. They also got premixes, cassava, corn or rice straw. Water was supplied in water troughs, filled twice a day.

The annual temperatures in Ho Chi Minh Ville/Saigon, Vietnam and Singapore, Malaysia are quite constant through the year, see Table 2 and Table 3.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean ºC	25.8	26.7	27.8	28.9	28.0	27.2	26.7	27.0	26.6	26.5	26.3	25.8	26.9
Mean daily max. ºC	31.5	32.9	34.0	34.8	33.3	31.9	31.0	31.3	31.1	30.9	30.8	30.6	32.0
Mean daily min. ºC	21.0	21.8	23.3	24.7	24.5	23.8	23.7	23.8	23.6	23.4	22.7	21.6	23.2
Mean relative humidity %	76.5	74.5	73.5	76.0	83.2	85.9	86.9	86.2	87.7	86.7	83.6	80.6	81.8

Table 2. Temperature and humidity in Saigon (World survey of climatology. 1984)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean ºC	25.6	26.1	27.5	27.1	27.3	27.6	27.3	27.1	27.0	26.7	26.2	25.7	26.7
Mean daily max. ºC	29.9	30.8	31.1	31.2	30.9	30.8	30.6	30.5	30.4	30.4	30.1	29.9	30.6
Mean daily min. ºC	22.9	23.1	23.6	24.1	24.5	24.7	24.7	24.4	24.2	23.9	23.7	23.2	23.9
Mean relative humidity %	85.1	83.3	84.2	84.6	84.4	82.5	82.0	82.5	83.1	84.1	86.0	86.0	83.9

Table 3. Temperature and humidity in Singapore (World survey of climatology. 1984)

The temperature is quite constant through the day but the sensation will change with the changing humidity. At a certain temperature, the humid air can hold more energy than air with less water vapour. When that air comes in contact with the skin it will feel sticky and warm, just like it feels when pouring water on to the hot stones in a sauna.

Totally 7 farms were studied. They are described below and in a short summary (Table 4).

Farm A

Farm A was situated in Cu Chi district outside Ho Chi Minh (Saigon). The family also had a café facing the street. They had 70 cows totally of which 36 were milking cows. It was the son in the family that seemed to be in charge. They had five employees that were preparing food, cleaning and milking. The grass was bought from some other farmers. Except from grass the cows were fed with some sort of fermented cassava and, as it looked like, minerals for pigs and also for cows. The minerals and cassava was mixed with water and served twice a day. Different cows got different amount of this slurry. The farmer estimated that the cows got about 60-80L water /day. If the water in this slurry was contained in that figure I am not sure. The cows were tied up and stood on concrete with rubber mattresses. There were no bars between them. The milking cows were under one roof and the young and the dry cows under another roof. The roof for the milking cows was metal and the other roof was with tiles. The breed was cross breed with a local cow and a Holstein bull from other countries, for example France and Korea. I would guess that this is true in some way, but there must have been more that 50 % Holstein in those cows if you ask me. They were hand milked twice a day but not when we were there. The farmer said that the mean production per cow and lactation was 5000 kg.

Farm B

Farm B was more in the countryside, but also in Cu Chi district. They had a lot of animals; pigs, hens, doves, a baboon, a small monkey, dogs, and a lot of birds. They had 40 cows and 10 were milking. The son in the family was doing most of the things himself and the mother were helping out a little but it was the father that had the control. They had had the farm since 1991. For food the cows got the elephant grass. But also some minerals and some feed made of a flower, coconut and cassava, mixed with water. Exactly what kind of minerals it was, I could not say, because they were packed in bags for cow minerals but they did not seem to come from a factory because they were closed with a rope. Water was given twice a day after finished milking, approximately 30 L each time. They had a bull from one of their own cows that was used on most of the cows. The cows were cross bread between Holstein-Frisian and local breed. The cows were tied up on concrete floor with no bars between them, some of the milking cows stood under a metal roof and some under tile roof. They were milked twice a day at about 8 in the morning and 3 in the afternoon. They were using a Spanish bucket milking machine, bought for around $ 1 240. We got two offers on how much the cows were milking, 2000 kg/lactation and 4500 kg/lactation.

Farm C

Farm C had a lose barn with 50 lactating cows in Cu Chi district. They were five people working with the milking cows and two with the dry and young cows. They had one veterinary and one veterinary assistant employed to handle the artificial insemination. They had one acre with elephant grass that they were cutting every day. The cows also got dry minerals when tied up for milking. The water was given in two big troughs per 25 cows, they were also used by the ducks to swim in. Because of the narrow aisle it might have been hard for all cows to drink as much as they needed. The water was changed every day. The cows were divided into two groups with 25 cows in each group. They had rubber mattresses on the floor in the aisle and in some of the cubicles. The cubicles were not used much and the cows seem to prefer the aisle. They used cross breed 75 % Holstein-Frisian and local breed and they had F2 and F3 (Figure 6) but also some with 75 %. The barn had metal roof and they used water sprinklers on the roof during the hottest time of the day to cool. The milking took about 2-3 hours using a bucket milking machine and was done at 7 in the morning and 2 in the afternoon. The cows were giving 4000 kg/lactation in average.

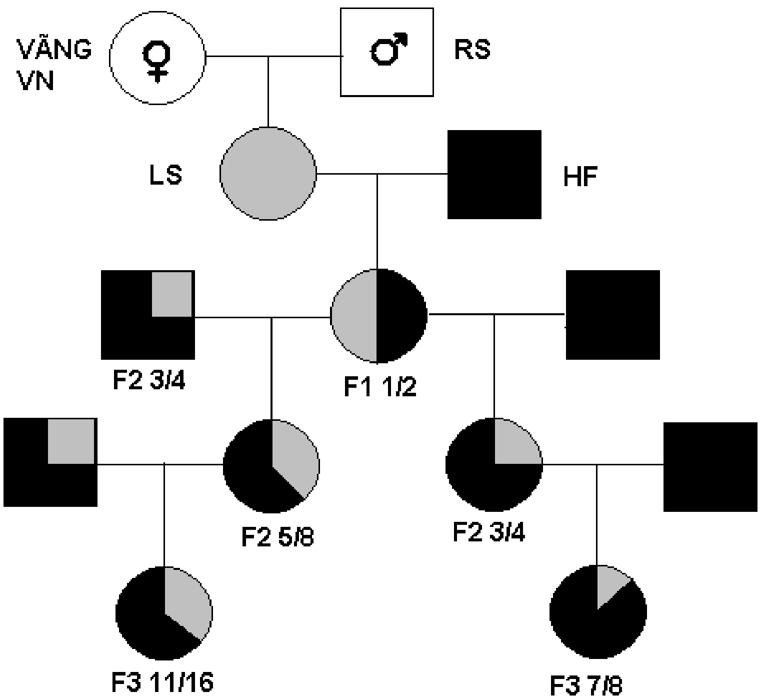

Figure 6. The breed chart

Farm D

Farm D was situated in Ba Vi outside Hanoi. The owner was a former information and telecommunication businessman. They had 12 employees working with the 55 dairy cows and 6 people with grass production. According to one of the owners the cows were eating grass (around 30 kg per day) and concentrate. The once milking more that 10 kg/day got 7 kg of concentrate and the once milking less got 4-6 kg concentrate per day. Pregnant cows got 2-3 kg of concentrate. The cows had free access to salt. At the farm they had tried to make silage of the grass but had not got any good result. Water was available in troughs, cleaned every day. The cubicles by the feeding alley were supposed to be used for resting but the cows seemed to prefer the alley. The building had metal roof and a sprinkler system like the one at farm C, they also had circulation fans in the ceiling and some extra standing on the floor. They were trying to have an opening to a grazing area but how much it was used they never told us. These cows were 100 % Jersey breed imported from Texas milking about 3000 kg/lactation. They had two milking machines but because of the problems with mastitis the cows were hand milked.

Farm E

Farm E in a village called Moc Chau had 4 milking cows out of 14 in total. The breed was probably a crossbreed between a Cuban breed and a local breed (we had a little conversation problem and it was an institute that supplied them with the sperm so they might not have known). They had three employees and also the family was helping out. The cows got grass that was much more like the Swedish grass. The complimentary food was not discussed, but the institute also had a feed mill that we visited that made concentrate for their farmers. Two of the milking cows stood in boxes and the other two were lose together with four of the dry cows. They were hand milked and according to the farmer were giving around 5000 kg milk/lactation. The farm was situated more in the highlands than in the tropics of Vietnam.

Farm F

Farm F was the first farm studied in Malaysia and is situated outside Sungai Petani. They had 56 cows of which 26 were being milked. The mean production per day was 6-7 kg and around 1500 kg/lactation (lactation is about 250 days). They used to be doing very well, but they had got problems with the management and the animal health had dropped. They said they were recovering slowly. Four employees were working with everything from cutting grass to milking. The food contained elephant grass and concentrate. The building was a loose barn system divided in six pens with concrete floor, containing cows and one pen with mud floor for the small calves. The roof was metal sheets and the feeding troughs were facing out from the building. Milking was done in a tandem-milking parlour with four cows on each side. The cows were placed in three groups of milking cows and then one group with dry cows, two with heifers and one with calves.

I noticed a peculiar thing at this farm, the cows were lying down close to each other despite the heat and the big holding pen.

Farm G

Farm G was the last farm visited in Malaysia and was situated outside Ipoh. They had 15 milking cows, some goats, turkeys, hens, dogs, peacocks, and a big fish. They had two employees working with the cows. The feed at this farm was different from the other farms, they were given chopped whole sweet corn and after milking they got a bucket of mineral feed in water to be shared by two cows. They had no water though, so before milking and after showering the cows they were moved to get some water. The cows were tied up with a feeding ally in the middle and had no bars between them, the floor was concrete and the roof cembonite. The breed was 78 % Fresian imported from Australia. Milking was done with a bucket milking machine, milking two cows at the time. The milk production was around 3500 kg/lactation. The low production depends on the short lactation 150-200 days.

Farm	Situated	No. of cows milking (totally)	Breed	Production level kg/lactation	Type of housing	Days of studies
A	Vietnam, HCM	36 (70)	X / Holstein	5000	Tied up	2
B	Vietnam, HCM	10 (40)	X / Holstein	4500	Tied up	2
C	Vietnam, HCM	50 (?)	X / Holstein	4000	Lose	2
D	Vietnam, Ba Vi	55 (?)	Jersey	3000	Lose	1
E	Vietnam, Moc Chau	4 (14)	X / Cuban?	5000	Box	1
F	Malaysia, Sungai Petani	26 (56)	X / Frisian	1500	Lose	1
G	Malaysia, Ipoh	15 (?)	X / Frisian	3500	Tied up	1

Table 4. Short summary of the farms.

Practical measurements to evaluate heat stress

The main objective is to evaluate different cooling systems in a hot and humid climate. To do so a method must be established. The intention is to assess heat stress on dairy cows. The respiration rate and hair coat temperate measures the physiological response. Air temperatures (dry bulb and wet bulb) outside and inside the building describe the thermal environment together with air velocity in the building, temperature of the ceiling and sunlight radiation.

The instruments needed for the registrations are thermometer, an Assman psychrometer a temperature and humidity logger, a watch, an IR-thermometer, a solarimeter and an anemometer.

Measurements were taken every half-hour between 9:00 to 17:00 (that will give 16 measurements during one day), or as long as there was time. The first three farms were visited on two different days to be able to register the variation in climate.

On each farm three cows with the highest actual milk production were selected and following parameters were registered.

Respiration rate, visual observation during 20 seconds and multiplied by three to achieve the breathing rate in breaths/minute. The observation was repeated two times.

Hair coat temperature by IR-thermometer at nine places (Figure 7) (Ehrlemark, 1991) to get an average surface temperature of the cow.

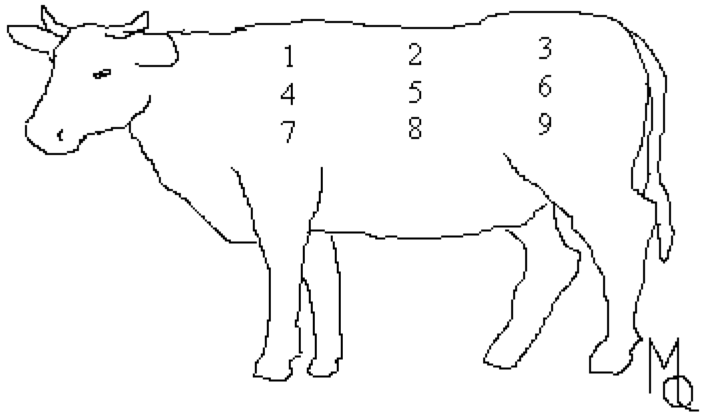

Figure 7. Locations where IR-temperatures were measured

To get total description of the thermal environment the air velocity, temperature and the humidity inside the stable, solar radiation and the temperature outside the building were measured and also the inside surface temperature of the ceiling was measured (IR-thermometer). To get the diurnal climate a logger was put in the building to register the humidity and temperature during the day and night.

Results and analyses of results

I had some technical problems with the temperature and humidity logger and therefor the measurements could not be used in the results.

Respiration rate

Respiration is considered to be a sensitive indicator of thermal comfort for cattle. Ehrlemark related the respiration rate (Breaths/minute, BPM) to the relative ambient temperature (RAT). RAT is aimed to show the influence of total heat production and therefor includes LCT (lower critical temperature), as a factor influencing the physiological response of ambient thermal conditions, eq (5)

$$RAT=(T_{ambient}-LCT)/(T_{body}-LCT)*100 \qquad (5)$$

(Ehrlemark, 1991)

T_{body} is assumed to be 39 °C, the hair coat about 5mm thick and the weight 500 kg.

Figure 8 shows the recorded respiration rate as a function of RAT. Each observation is a mean value of the cows, measured at the farms every 30 minutes. Farm A, B and C have observations for two days.

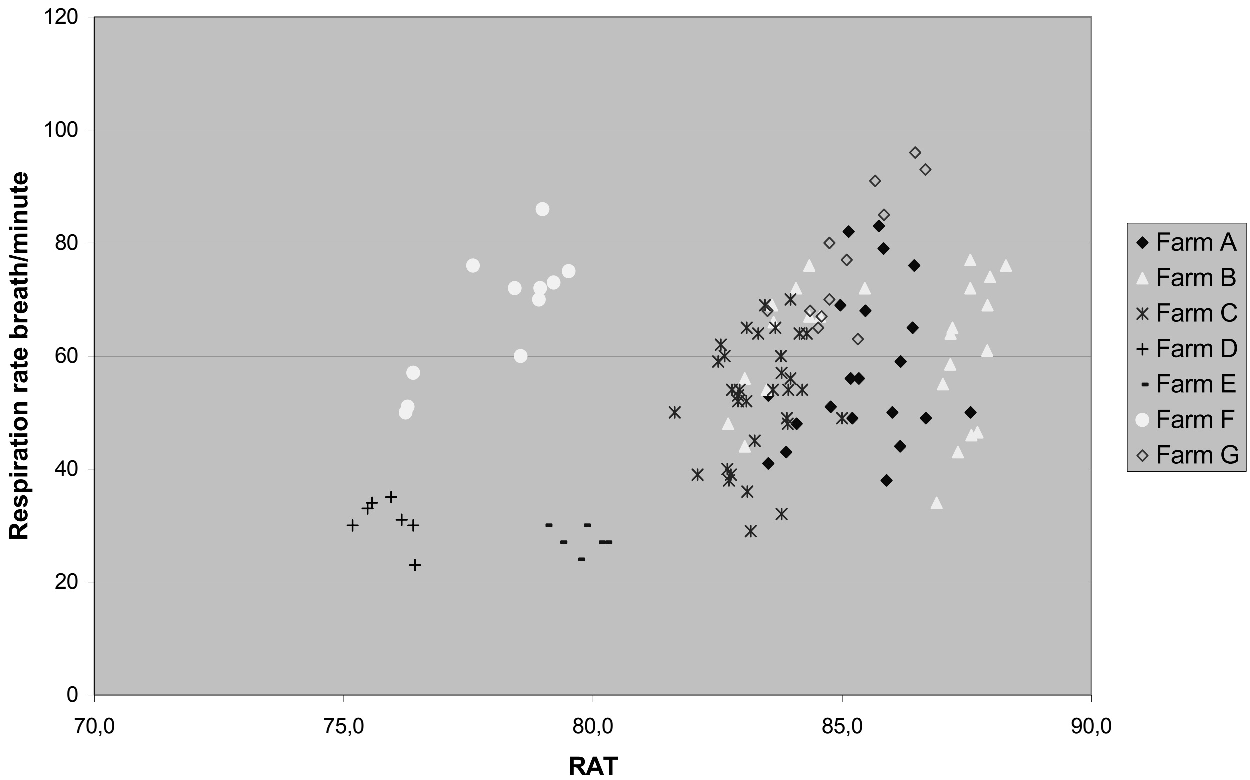

Figure 8. Respiration rate in relation to Relative Ambient Temperature (RAT)

General comments of the results presented in Figure 8.

- In a relation between high RAT and high breathing frequency could be seen.
- Farm F is placed a little bit to the left compared to the other farms, the reason for that could be explained by the low milk production and high ambient temperature. Compared to farm G the ambient temperature was around the same, but the cows on Farm G had higher milk production The probability that the cows at Farm F were on heat could also be affecting the cows this way.
- The effect of low milk production could also be seen on Farm D. RAT is low but so is the breathing. The ambient temperature was about the same as the one on Farm E.
- Even more obvious is this relation on Farm B, the figure shows two different groupings' line. One group is from day one and the other from day two. There were four days between the visits and the milk production had dropped from 28 to 22 kg/day and by that the RAT.

Individual comments on the relation between RAT and BPM:

- Farm A had a high production with a mean value of ~27 kg/day, according to the farmer. The weather was quite hot, the highest and lowest temperature measured in the building 29,7 and 25,5 °C the first day and 30,6 and 29,0 °C the second time, three days later. Mean THI was 75. When both temperature and production is high the RAT gets high as well. The breathing rate is spread on a big range depending on some rain the first day.
- Farm B also had high production, ~25 kg/day. The weather on this farm was hot, one day between 30-32 °C and five days later between 31-32 °C. Mean THI was 81 for both days. Although the temperature is around the same both days the RAT is very different between day one and two. The explanation to that could be that the milk production had dropped from 28-22 kg/day and therefor also the RAT. BPM was about the same both days.
- Farm C with a milk production of ~15 kg/day which is not that high. The temperature was between 28-32 °C the first day and 31-32 two days later. THI was 81 as a mean of the two days value but there was a breeze coming through the building.
- Farm D had a low production ~10 kg/day and also temperatures around 25 °C, it was raining, which gives a low RAT. THI was also low, 75. The cows at this farm were an other breed (Jersey) that is considered to withstand heat better than Holstein and Frisian, (the breeds the other farms used).
- Farm E had as high production as farm B ~25 kg/day but there had been cool rainy weather for about a week and the temperature was around 22 °C. THI was 70, the lowest on the farms where measurements were made.
- Farm F with ~6 kg/day and cow has a low RAT because of the low production level. The weather was hot (28-32 °C) and THI at 80. In the figure the breathing rate with its high numbers, shows that the weather effected the animals.

- Farm G, had the hottest weather of all farms with 28-33 °C, THI was 80. Milk production was ~23 kg/day and cow, which makes the RAT high. Also breathing rate was the highest of all farms.

Looking at the farms and the animals one by one gives a better understanding of the climate and the animals' response to the climate.

Generally it was seen that the respiration rate is increasing in average (90,9 %) during the day (after 08:00) and very often rapidly dropping around 15:30 when the cows are showered before milking.

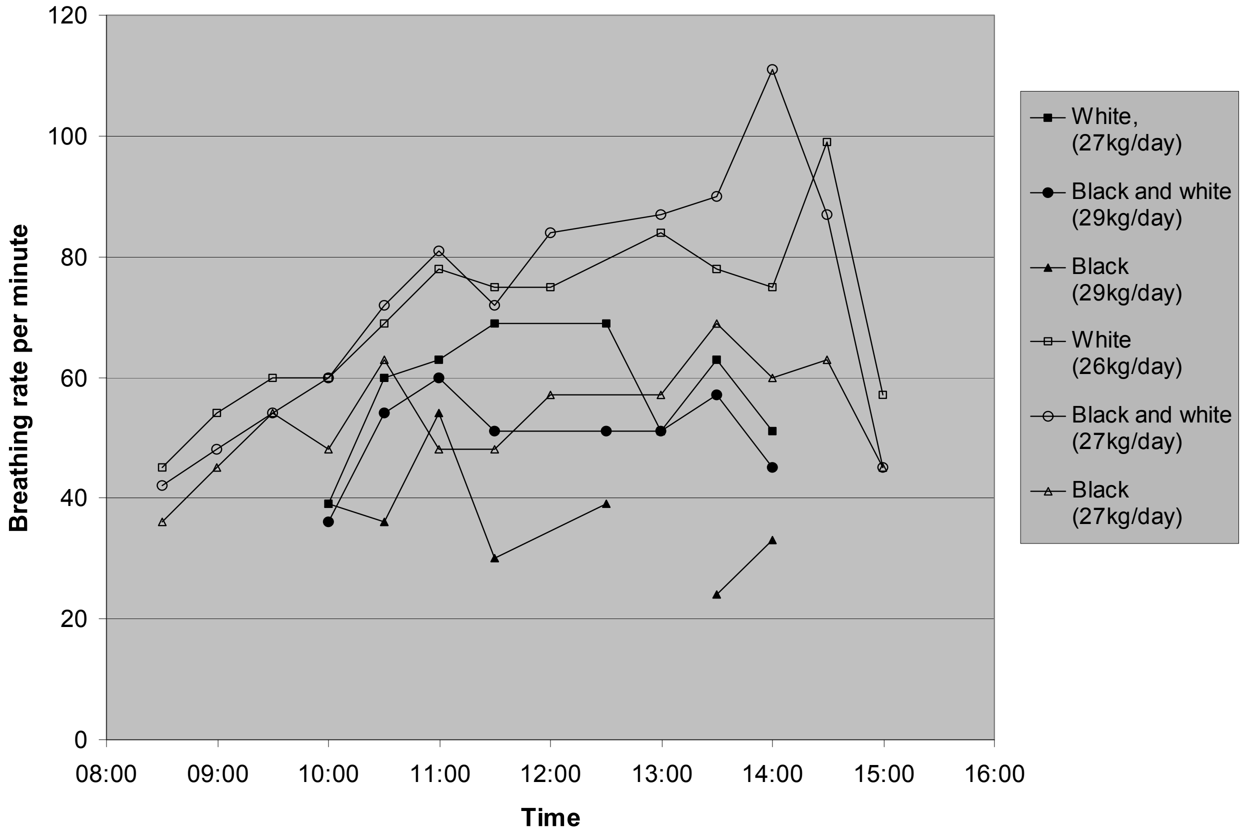

Figure 9. Breathing rate on three cows; white, black and white and black during the day at farm A (day one filled marker, day two none filled marker).

Farm A (Figure 9) At this farm measurements were taken twice and as we can se, the cows were more stressed the second day (none filled marker). The weather on the first day was cloudy and there were also some showers in the afternoon. The second day was much warmer and no rain. At 15:00 the cows were washed before milking, which is easily seen in the figure. Normal breathing rate is 15-30 breaths/minute (Stowell, 2000). Above 80 breaths per minute is considered heat stress.

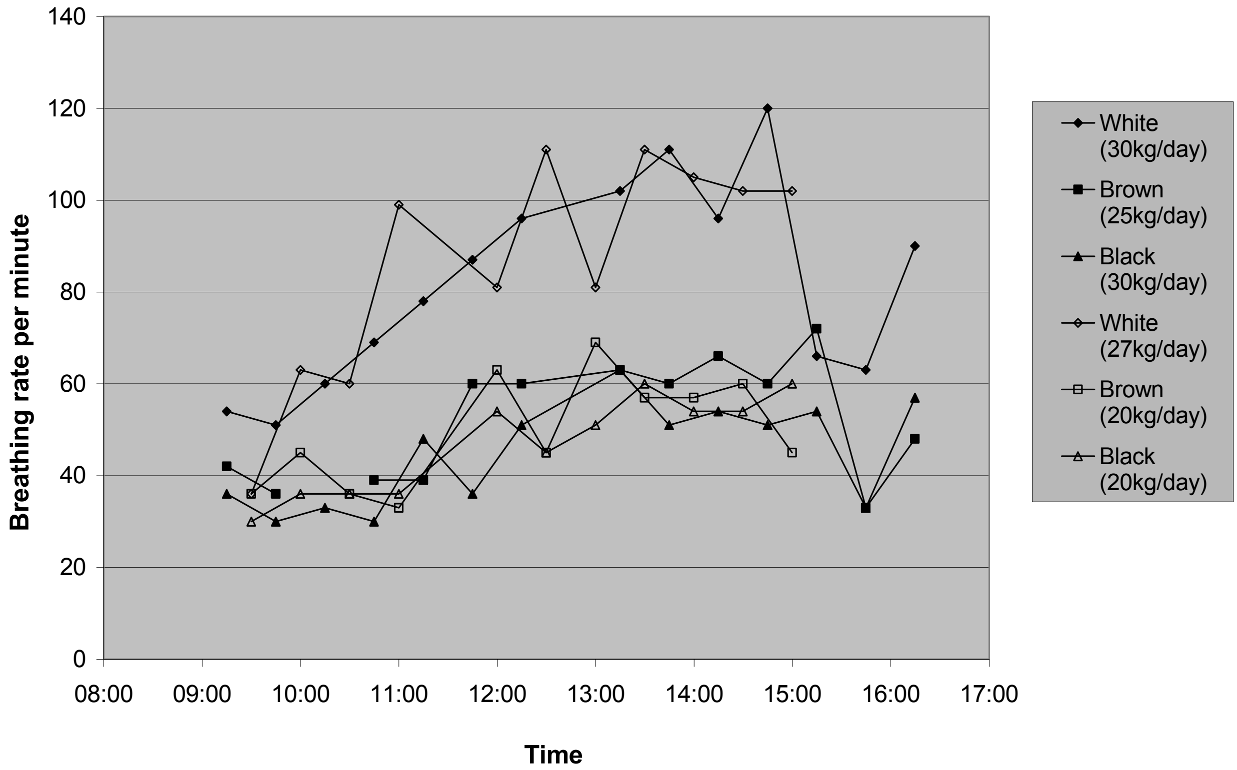

Figure 10. Breathing rate of three cows; white, brown and black during the day at farm B

Farm B (Figure 10) was also situated in the Cu Chi district. Also on this farm two days of measurements were made (day one filled marker, day two none filled marker). The weather was about the same both days. The white cow had high breathing frequency both days, which could be explained by the direct sun she got from standing at the end of the building. The white and the black cow are milking the same amount of milk the first day, but they seem to experience the heat differently. At 15:30 the breathing curve drops when the cows were showered before milking. Only the white cow is clearly suffering from heat stress.

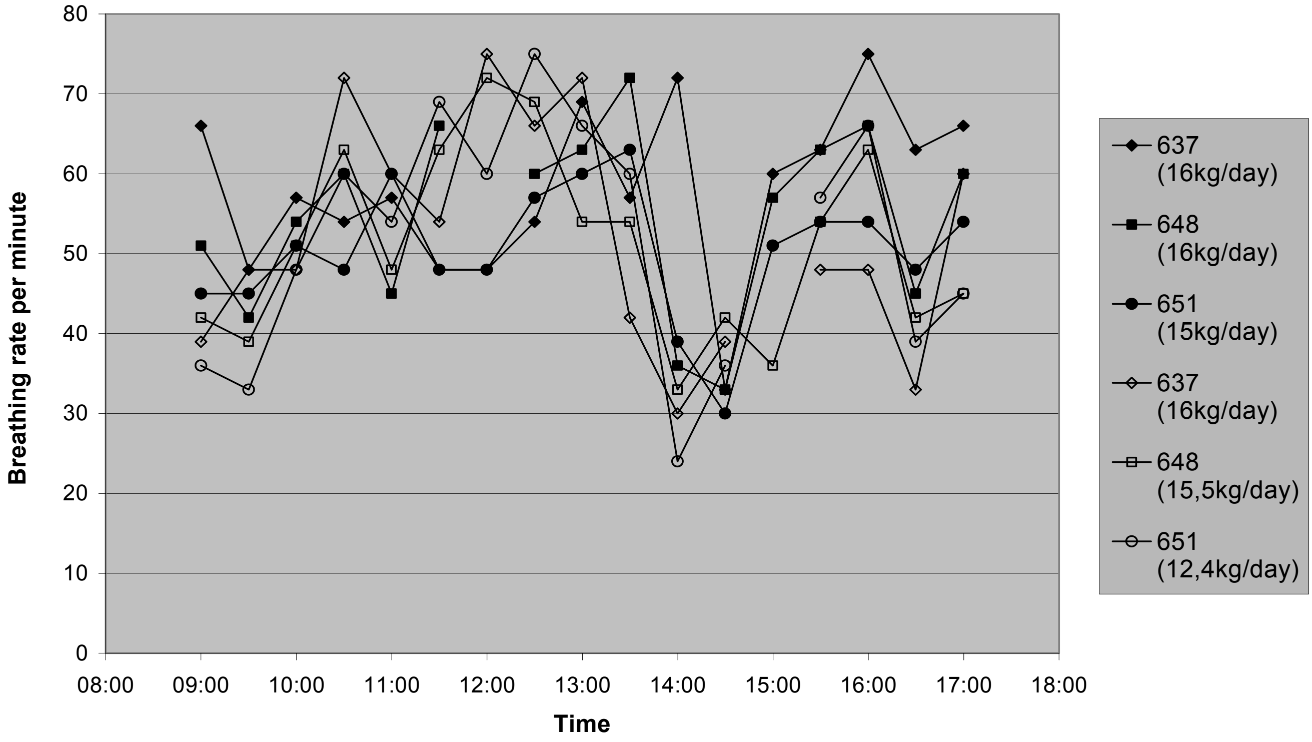

Figure 11. Breathing rate of three cows; 637, 648 and 651 during the day at farm C

Farm C (Figure 11) with 50 milking cows also located in Cu Chi district. At the farm measurements were taken during two days and the second day the workers forgot to start the watering of the roof, which can be seen in the figure. At 13.30 the floor was washed, the cows tied and cleaned, they were fed and milked. Milking took about 2-3 hours, the decrease in breathing rate at 16.30 could be the response of finished milking and access to water again.

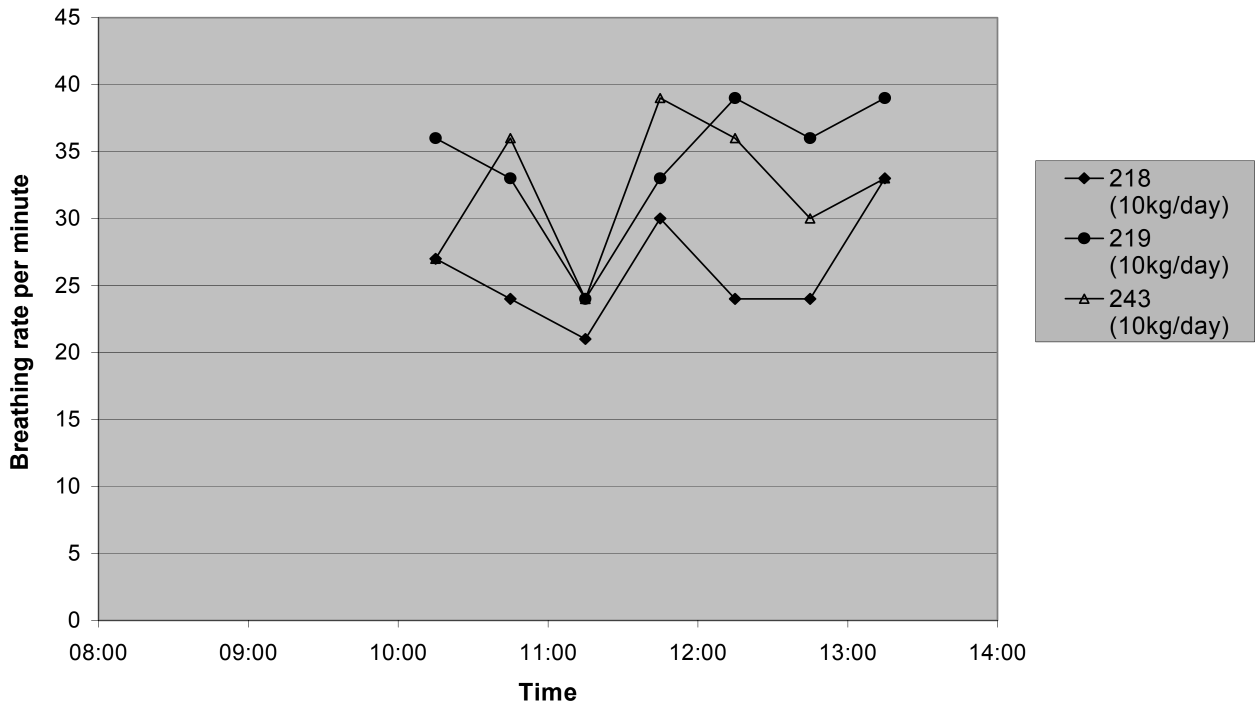

Figure 12. Breathing rate on three cows; 218, 219 and 243 the day at farm D

Farm D (Figure 12) in Ba Vi has 100 % Jersey breed. The day the measurements were taken the weather was quite cool, it was raining heavily and there was a nice breeze. The fans in the ceiling were on but the ones on the floor were turned off. I have no good explanation why the breathing rate is lowered at 11:15, but it might have been that it started to rain more heavily. Notable is that the breathing rate is quite low the whole day.

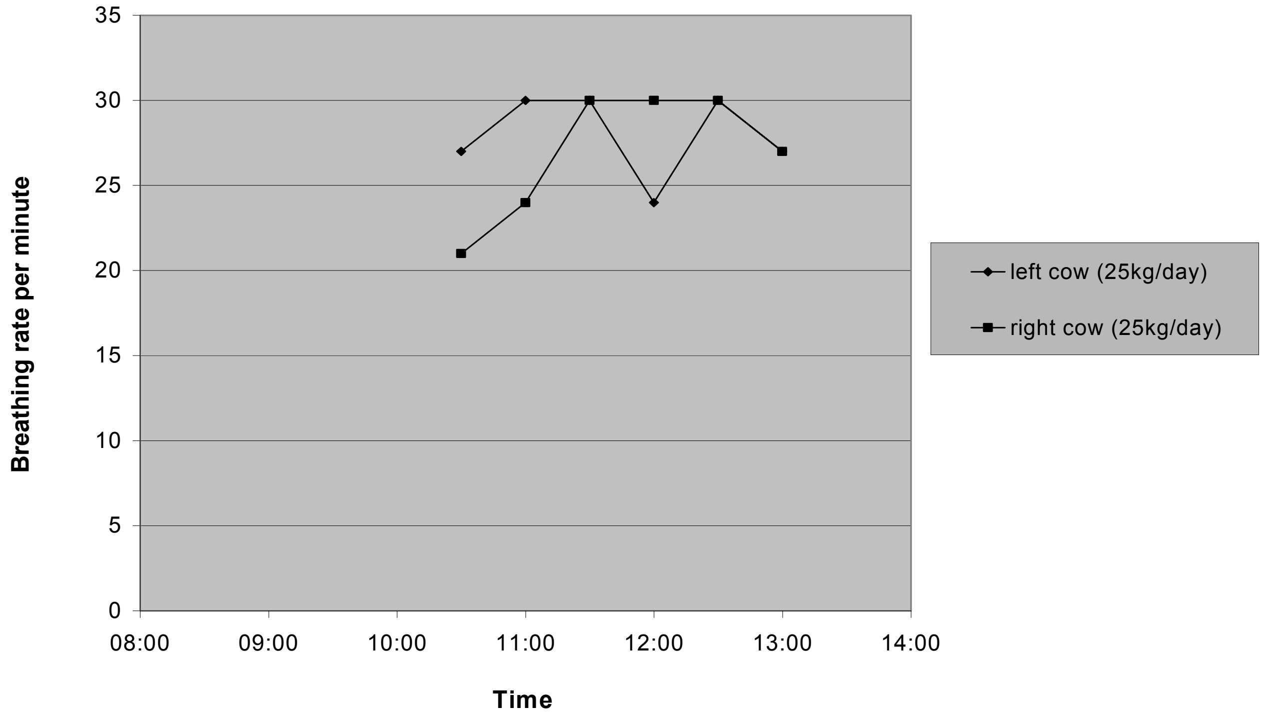

Figure 13. Breathing rate on two cows, left cow and right cow during the day at farm E

Farm E (Figure 13) was situated in the mountain area of North Vietnam, the town was called Moc Chau. It had been raining for five days and it was still raining when the measurements were made. Two of the milking cows were placed in pens, the ones measurements were made on and the other two were in a loose housing barn with three others. The cows were not showing any tendency of heat stress.

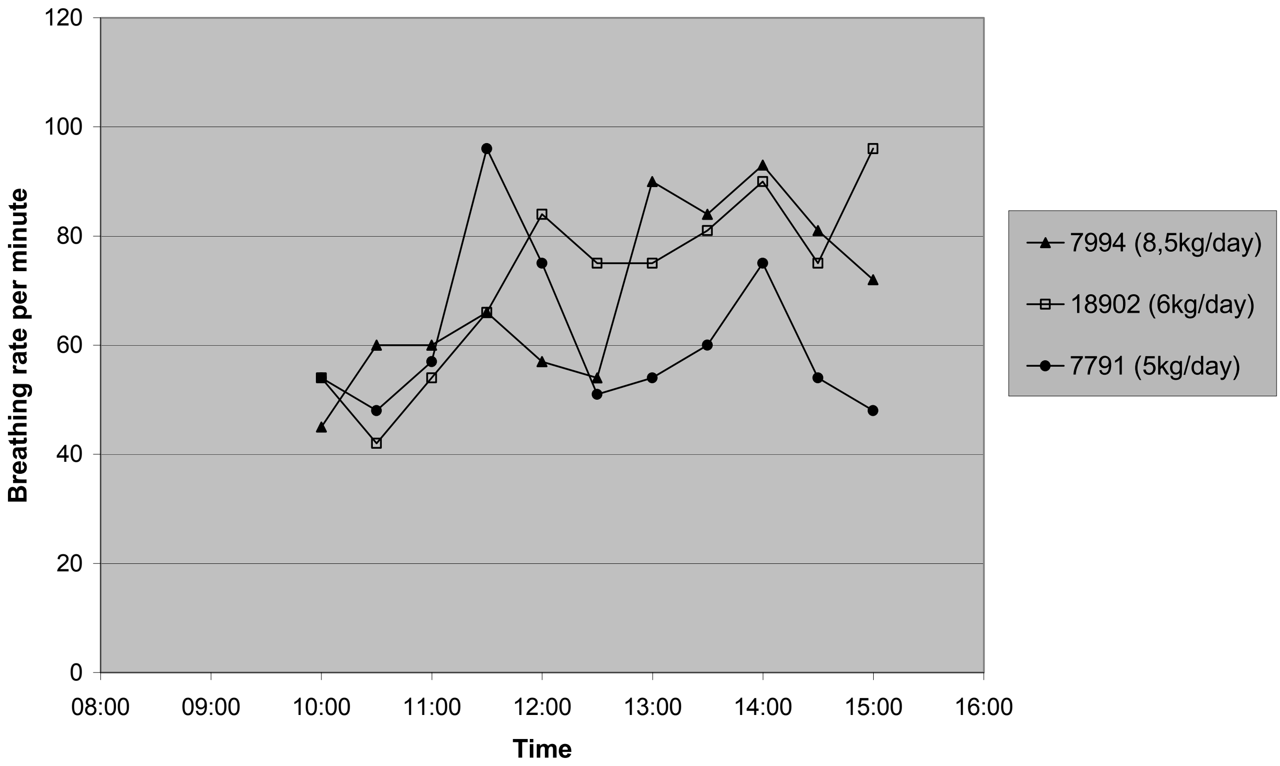

Figure 14. Breathing rate on three cows; 7994, 18902 and 7791 during the day at farm F

Farm F (Figure 14) in Malaysia outside Sungai Petani. The weather was really warm during the day. The cow with number 7791 was in one pen and the other two in another. The breathing rate of cow 7791 is not similar to the other two and also it is very unstable. A thought might be that cow 7791 is on heat and therefore shows different breathing pattern than the others. All cows were milking very little, but it might have been at the end of lactation. At 14:00 the cows got fed and they were standing in the sun by the time they ate, as can be detected by the increase in breathing rate.

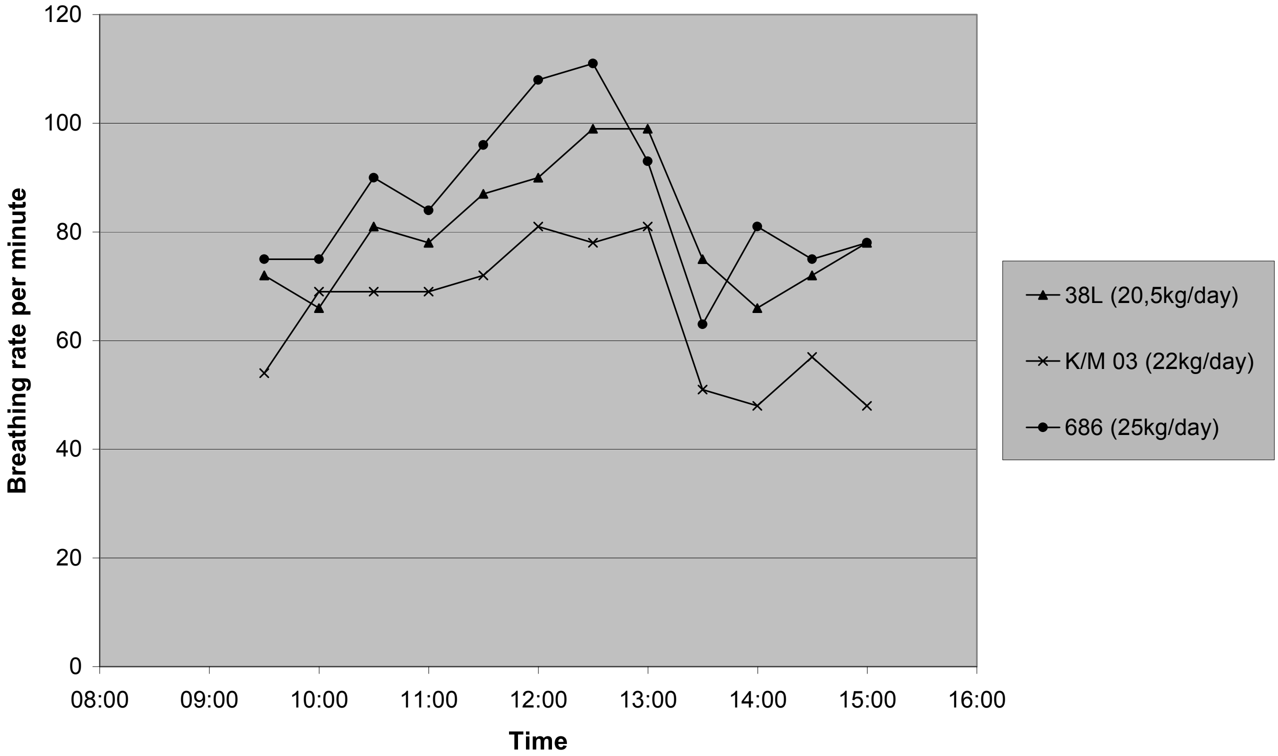

Figure 15. Breathing rate on three cows; 38L, K/M 03 and 686 during the day at farm G

Farm G (Figure 15) outside Ipoh the weather was warm but in the afternoon at 14:30 it started to rain. At 13:30 the farmer washed the cows and the floor, which is seen in the figure. The cows were breathing very heavily, almost hyperventilating the whole day. Compared to the other farms in this experiment these cows had the highest breathing frequency.

One hypothesis is that breathing rate is a function of THI at different production levels (Figure 16). The higher production level the higher breathing rate compared to THI.

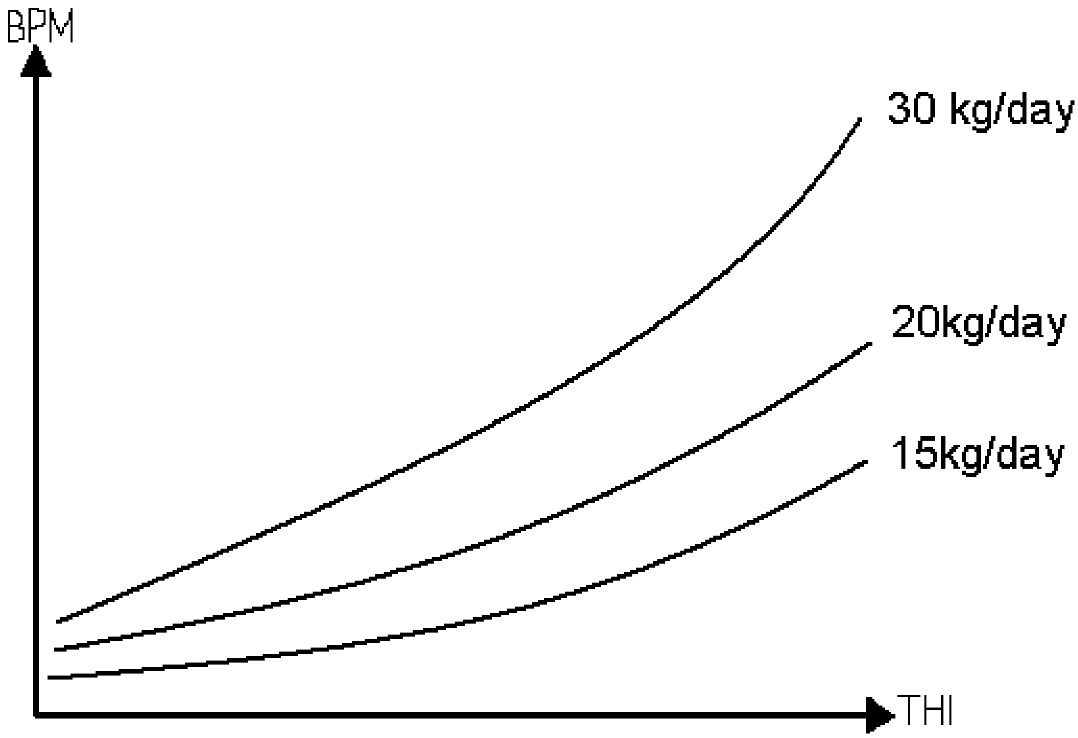

Figure 16. Hypothesis that breathing rate is a function of THI and production level.

Testing the hypothesis with the collected data resulted in Figure 17. The cows at a milk production level of 27, 25 and 16 kg/day followed the hypothesis. The line at a milk production of 20 kg/day has a very near range of THI, which is the possible explanation to the line not following the expected look. The line showing the trend of the production of 30 kg/day is lower than expected relation. The normal breathing rate is around 15-30 BPM according to Hahn 1997 and that means that the asymptote should show this. The R^2 –values are 0,665 for 25kg/day, 0,246 for 27 kg/day, 0,0155 for 30 kg/day, 0,047 for 16 kg/day and –0,01 for 20kg/day.

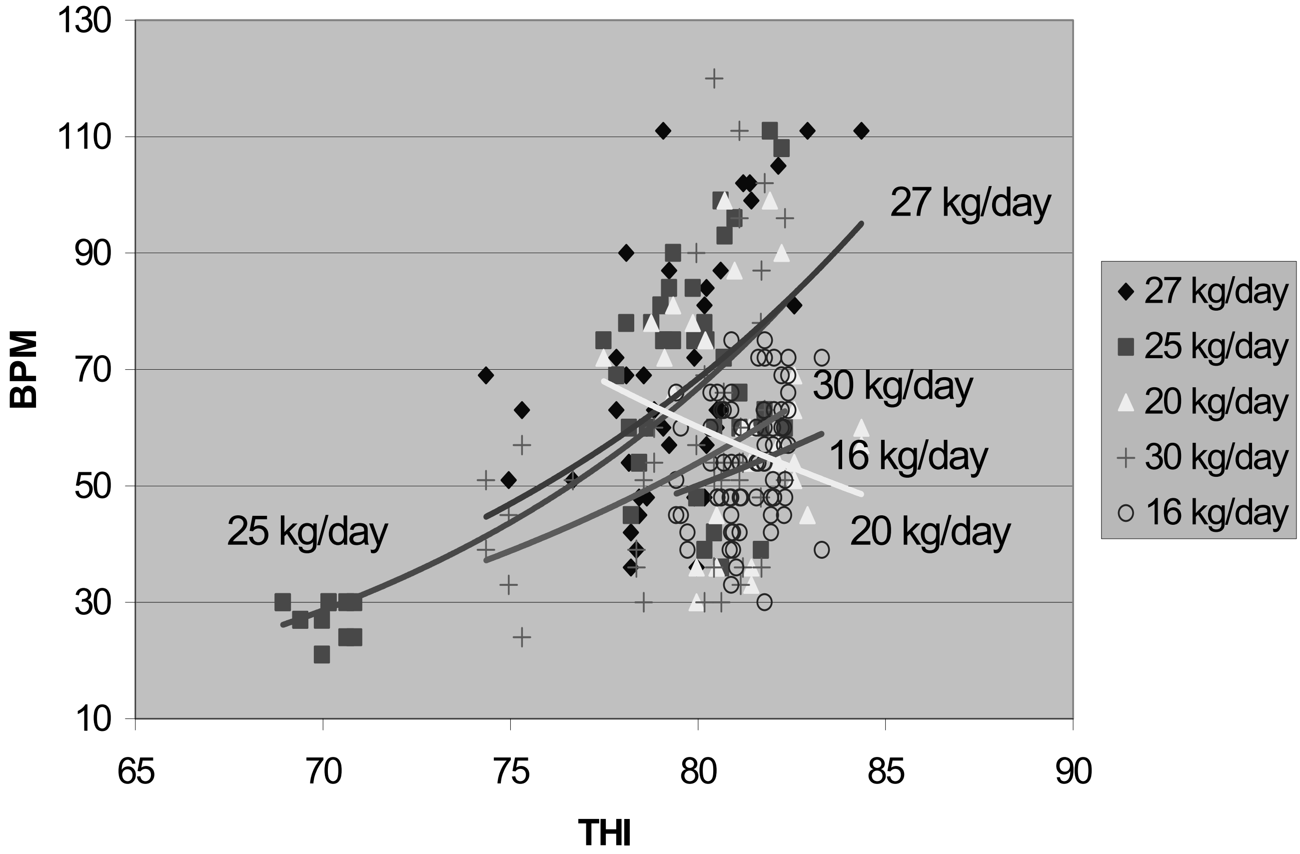

Figure 17. Respiration rate as a function of THI at different production levels.

The second hypothesis is that the respiration rate is exponential to the coat surface temperature. To be able to se if the production level has an effect on the breathing and surface temperature the legends are different on different production levels in Figure 18.

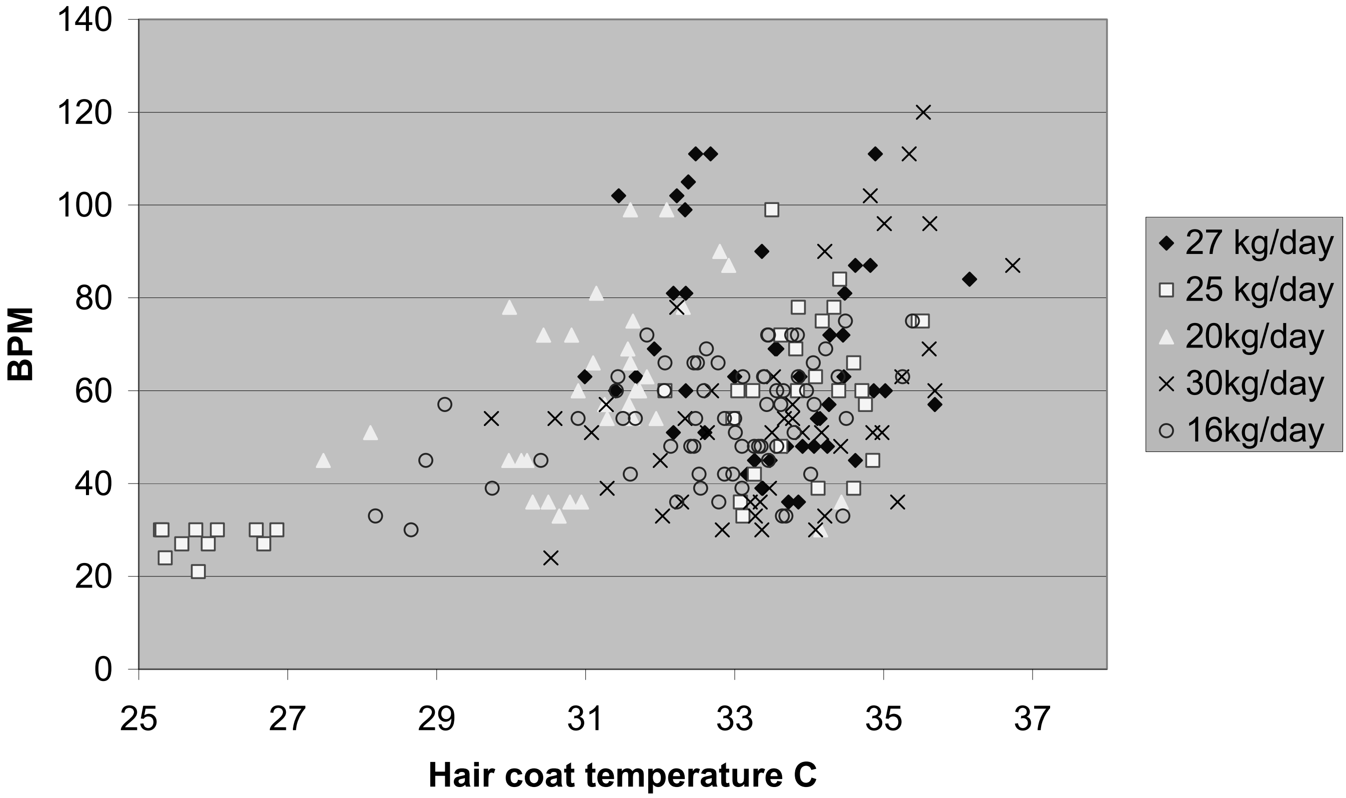

Figure 18. Respiration rate compared to coat surface temperature and production level.

It is not a clear difference between the production levels but Figure 18 does give an indication of the asymptote towards 15 BPM and also a asymptote at the coat surface temperature near the body temperature (38-39 °C).

Hair coat surface temperature

The temperature of the hair surface of the cow was used to give an idea of the body temperature and the heat regulation system.

Generally the hair coat temperature reflects the total affect of thermal environment and thermal regulatory system of the animal. In warm and hot condition the animal minimise the thermal resistance in the body layers (vaso dilation) and the hair coat is also adjusted to minimum heat resistance (cows should have the hair coat cut). However under conditions when ambient thermal condition exceeds body temperature the hair coat should be insulating to reduce heat transfer from the surroundings into the body. In Figure 19 the measurements above 30 °C, ambient temperature, are decreasing on the coat temperature axis, the explanation to that is among other things the showering of the cows. The cool weather on farm E is the explanation to the measurements below 30 °C coat temperature and below 30 °C, ambient temperature in the figure. The line in the figure shows a formula found through practical experiments made by Thompson et al. (1952). The measurements indicate that the fur of these animals has more insulation than the ones in the earlier made experiment, by the lower values of coat temperature. An insulating fur is making the animal less affected by heat coming from the environment, but of course it will be more difficult for the animal to dissipate the heat production in the body.

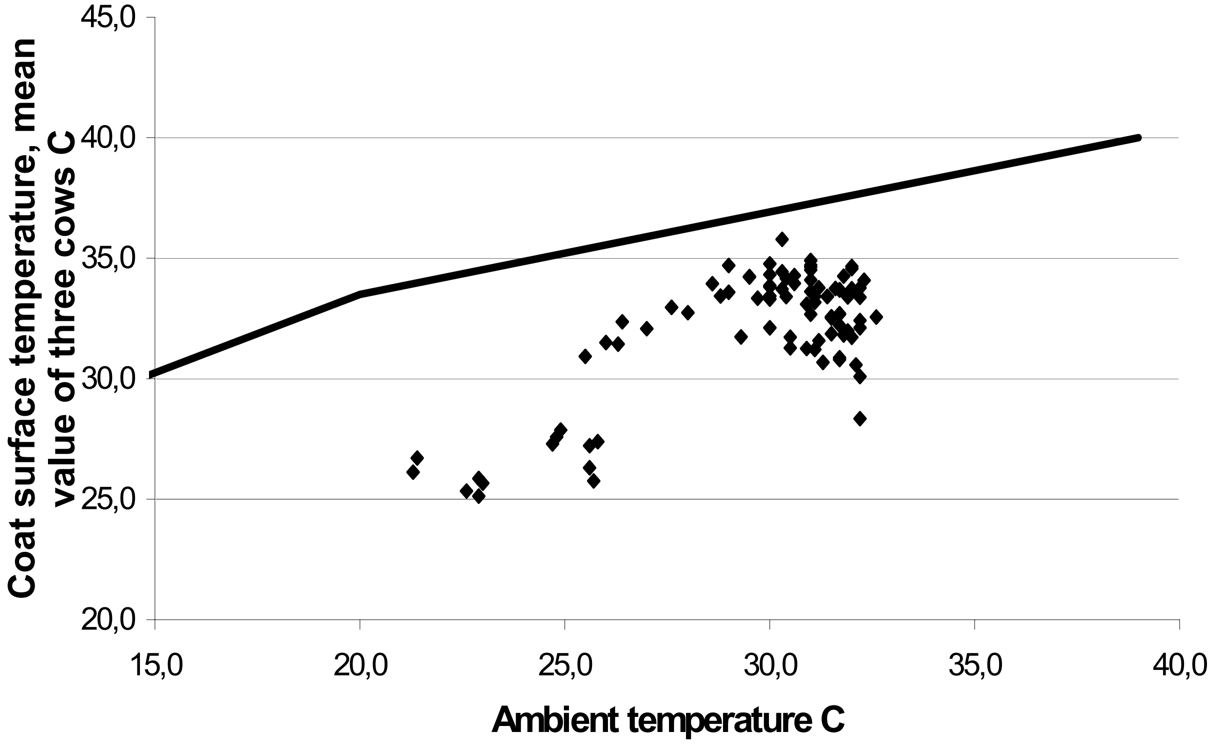

Figure 19. Coat surface temperature in relation to ambient temperature.

To see what the wind could do to cool the animals a simulation program called Anibal (made by Ehrlemark and Sällvik 1996) was used. The program is able to calculate the temperature of the surface of the hair coat layer given certain values of thickness of hair coat, weight of the animal, production level and air velocity. These calculated values were compared to the measured temperatures of the hair coat surface of the cows. Estimation was made that the fur was about 5 mm thick. The measurements that were taken on newly washed cows and the one standing in direct sunlight were erased from the comparison (Figure 20). The R^2-value is 0,2814, which is quite low. If the observations were divided farm by farm the R^2-values became better than the average on some farms and lowered on some.

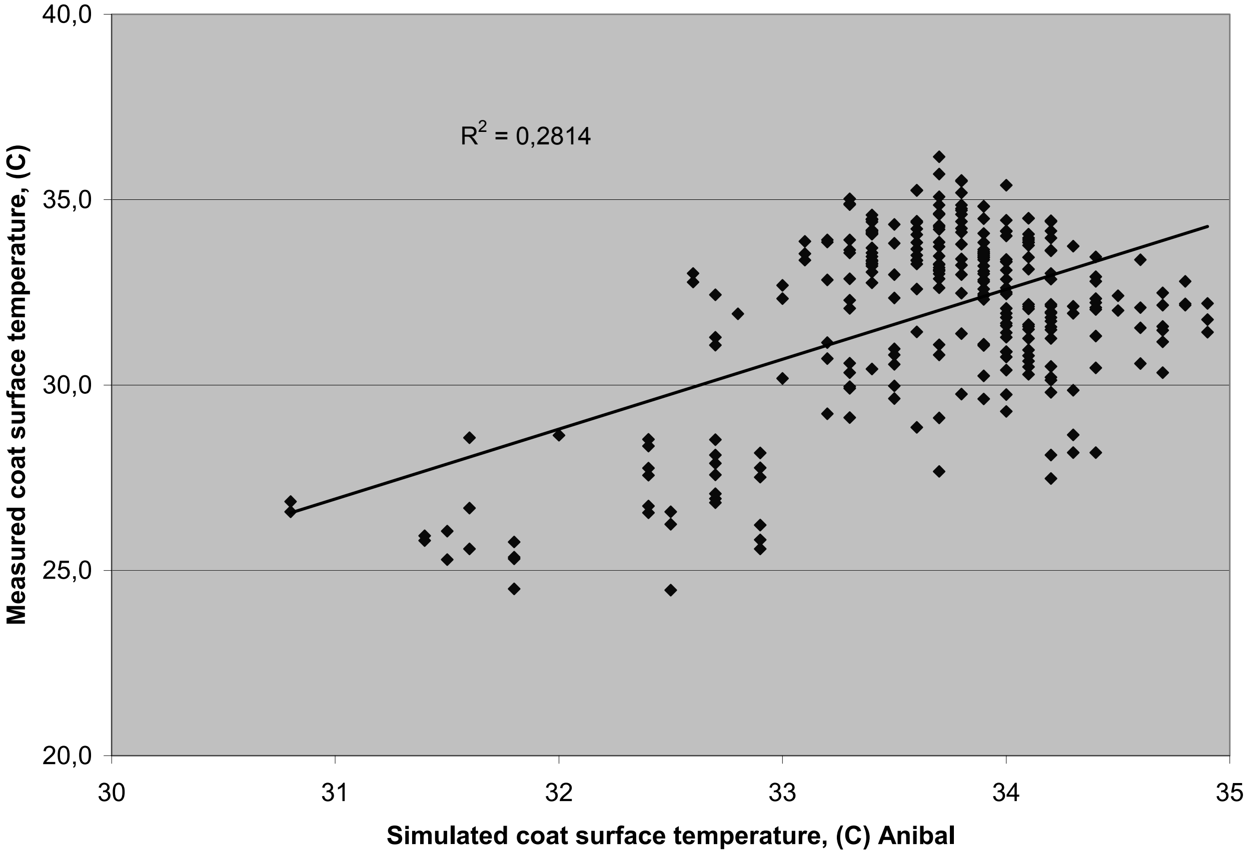

Figure 20. Observed coat surface temperature compared to simulated coat surface temperature by Anibal (Ehrlemark and Sällvik 1996)

Temperature Humidity Index, THI

THI stands for Temperature and Humidity Index and is used to explain the thermal influence of humans and animals by different combinations of temperature and relative humidity. As a guideline when transporting animals, stress categories for different THI values have been set. THI below 75 means no heat stress, THI between 75-78 means be alert, THI between 78-83 is danger and above 84 emergency (USDC-ESSA, 1970). In Figure 21 the observed THI of the farms are shown in a diagram with the horizontal lines representing the stress categories. Farm D and E are in the “no stress” category. That means that the cows should not show any reaction on heat stress because of temperature and humidity. And this is supported by the observations of the respiration rate. Most of the measurements in Figure 21 are in the “danger” category, that means cows are affected by heat stress which is also confirmed by the breathing rate.

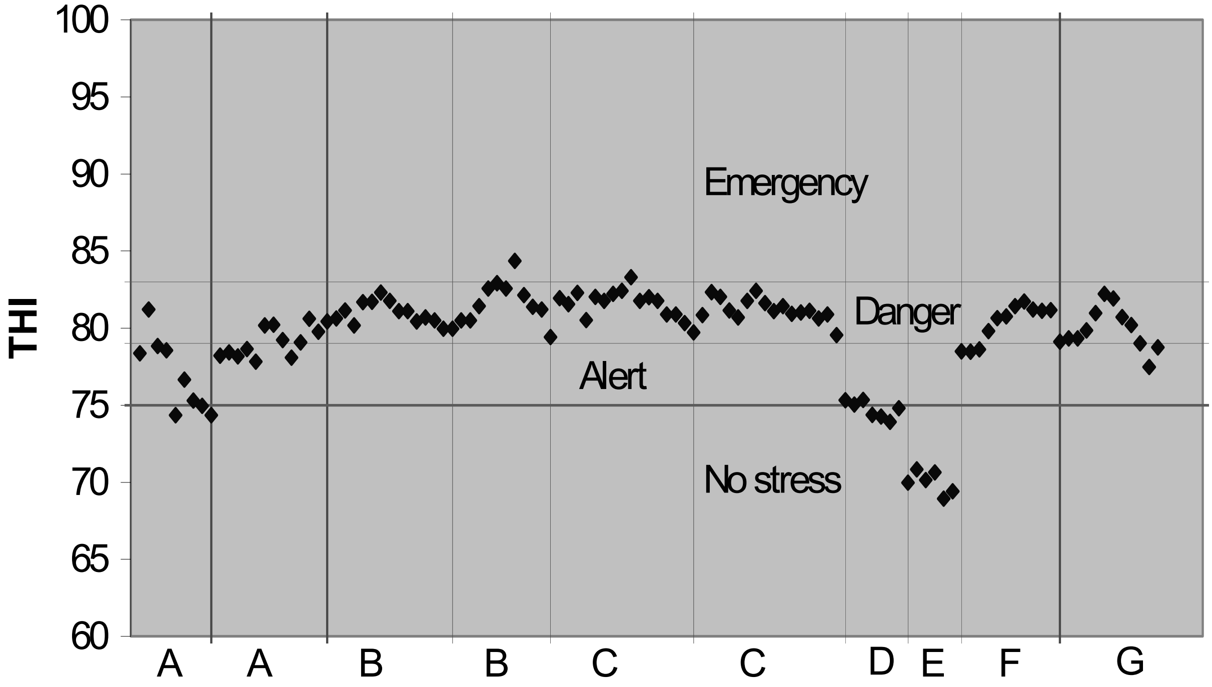

Figure 21. The USDA categories of heat stress for cattle and associated THI values from the different farms (A to G) and days.

Air velocity

Increase of wind or air velocity is an important way to reduce heat stress by decreasing the heat resistance of the boundary layer. This will facilitate the dissipation of sensible heat from the body more effective. For good cooling effect increased air velocity should be combined with sprinkling of water directly onto the cows. The results of wind in the investigations are very difficult to analyse and comment. But consideration has been taken in both the simulation of surface temperature and in RAT.

Decline in milk production

A cow exposed to increasing heat stress will be less comfortable and proportionally to stress level she will reduce feed intake and hence milk production (Figure 22).

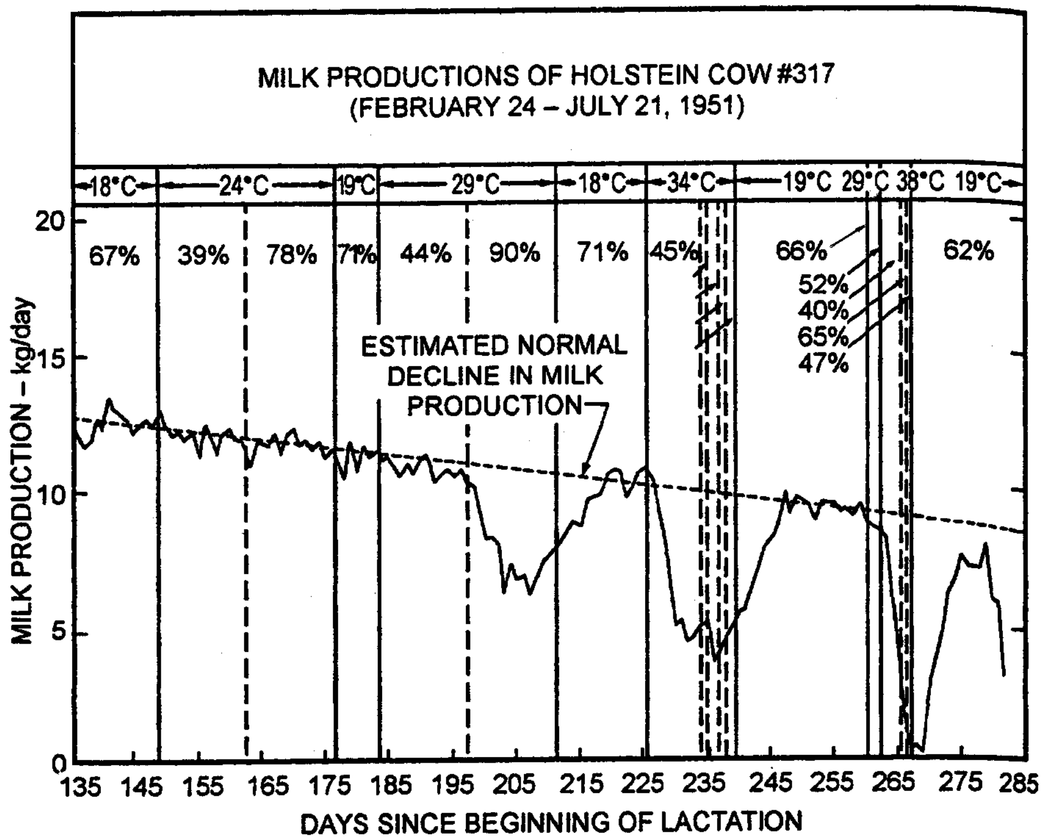

Figure 22. Milk production decline of one Holstein during temperature-humidity test. (Yeck and Stewart, 1959)

The milk reduction because of a hot environment could be more or less, depending on how much milk the cow would give if the environment were more optimal. The difficult thing is that you do not se the money you are loosing because it is a loss of income. Also it is hard to say how much of the losses that are depending on the climate and how much is because of other things, for example feed, diseases and management.

Using the milk decline formula, eq (3), the great majority of the cows in the actual investigation had a deceased milk production by median 7 kg/day and cow and a normal production of 27 kg/day. It should be noted that the temperature and humidity are only measured during the day.

The milk price for a farmer in Vietnam is between 1800-3650 Đ/kg milk, that is 1,10-2,40 SKr ($ 0.12-0.24) depending on the transport to the nearest city. That means that a farmer could lose around 12 SKr/day ($ 120 /day) and cow due to reduce milk yield of heat stress. Another thing is the decrease in fertility and therefor less milk that could be expected. If it takes to long time to get the cow pregnant there might not be a profit in keeping her.

Roofs

Measuring the temperature of the inside of the roof would give us an idea of how the material of the roof would impact the thermal environment by radiation on the cows. To estimate this radiation influence of the roof a black globe thermometer should be used. Unfortunately there was no black globe thermometer available, so those measurements could not be done. The problem with using an IR-thermometer is that it is measuring one point only. To get a representative value several points must be measured to form a mean value. The mean value of three to four measurements on different places of the ceiling was assumed to give a correct value.

The farms had three different materials in the roofs, metal sheets, tiles, and cembonite (corrugated cement sheets armed with fibres). In Figure 23 the inside surface temperature of the roof is showed as a function of the temperature in the shed for the roof materials found in the investigation. The day when the measuring of the cembonite was done at farm E was cool and rainy which makes it hard to say anything about the material. The tiles seem to give about the same inside surface temperature of the roof as the inside air. For metal sheet the inside roof surface temperature could be 8 to 10 °C higher than inside air temperature. The difference between metal sheet and tiles depends on the lower conductivity. Tiles can keep water within itself and therefore have a buffer before it gets hot. On that farm they were sprinkling the roof during the hottest time of the day.

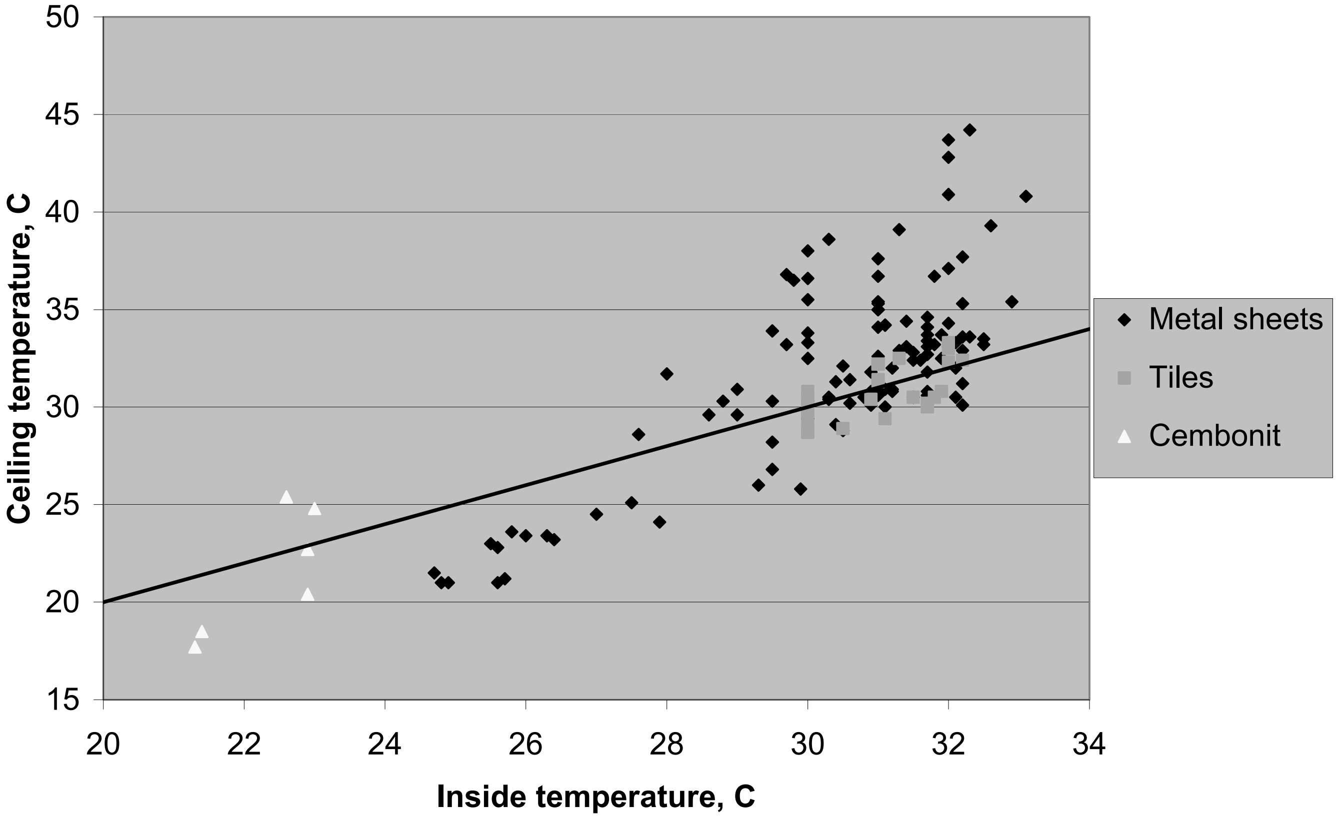

Figure 23. the relation between inside roof surface temperature and inside air temperature for different roof materials.

Problems with water

Farmers have to be taught the importance of water being available to the cows, and the importance of the quality of the water. At one farm the bull stood just by the water tank, and when he was urinating it was splashing into the tank. The water was than used for drinking and cleaning the milking equipment. Also ducks and hens were walking and swimming in the water-through on some of the farms. Dirty water could in some cases be a bigger problem affecting the quality of the milk and also the amount of milk the cow is giving, than the heat.

The intervals between milking could also be a decreasing faction to the milk production. If the cow would get as much time to produce milk between morning and evening milking as between evening and morning milking the production would be able to increase.

The food composition could be better, not only by using other types of grass (if possible) or concentrate but also by taking samples for simple analysis to see what they are getting and what is missing.

Conclusions

Keeping dairy cows with a good milk yield in a hot and humid climate is possible, the difficult thing is to make them produce as much milk as we want. An optimal climate could be achieved with an air conditioner in a closed barn. But there are other ways that are more realistic and should be tried first.

The first thing to do is to make sure that cows are kept in barns under shed and not in a grazing paddock. Avoiding direct sun-radiation will give much better prerequisites. The importance of good fresh water available all day and night could not be told enough. The water does not give watery milk, as some of the farmers seem to think. Cooling with showers directly on the cows is a way of helping the cows to decrease heat but the water used in showers and cooling equipment must be clean to avoid spreading of diseases.

Systems based on water evaporation are better suited in hot dry climates than in humid ones. But the practical study in this thesis showed that breathing rate decreases and so does the temperature of the skin. The farmers might not be aware that they are cooling the cow when they are washing them before milking. The washing is necessary because the cows become very dirty. I assume the cows will lie in the manure to cool and also when they are tied up they do not have much choice where to lie.

The other way to cool mechanically is with fans using volume of air, cooled air or air combined with water. What should be used depends on the building and economy. In the small farms studied in the practical study a big investment is hard to defend but in more intensive and big farms a cooling system could be more convincing.

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Appendix

Nomenclature

Ambient temperature:	The surrounding temperature.
Dry:	About a cow; a non-milking cow.
Embryo:	The early stages of development before birth, and before foetus.
Follicular:	A bubble in the ovary that contains a mature ovum.
Hyperthermia:	When temperature is above normal, (higher than 41ºC)
Hypothermia:	When temperature is under normal
Oestrus:	The time before ovulation when the cow shows that she is ready for fertilisation; the cow is "on heat".
Oocyte:	The ovum cells, produced in the ovary.
Mastitis	A bacterial infection of the udder which produces with flakes or cheesy clots in the milk. Also called garget, mammitis, udder-clap.
Udder:	The mammary gland of female animals, the pendulous and baggy organ which secretes milk and is provided with nipples through which it can be drawn.