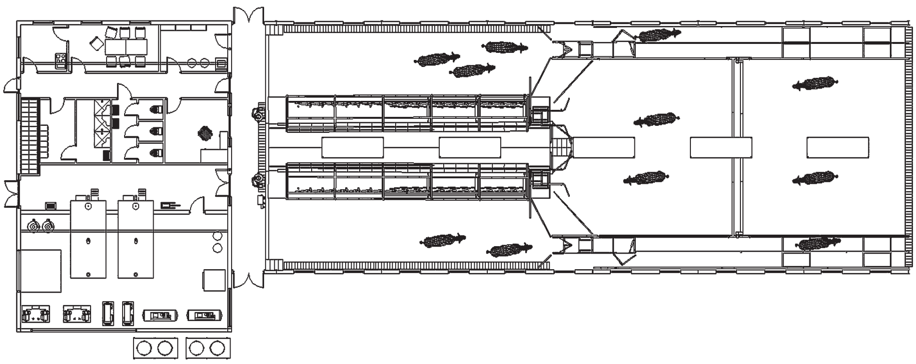
Design proposal for milk centre with mechanical cooling for dairy cattle in tropical climate

Byggnadsförslag för mjölkningsstall med mekanisk kylning för kor i tropiskt klimat



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Examensarbete för agronomexamen

Keywords:
dairy production, heat stress, mechanical cooling, tropical climate

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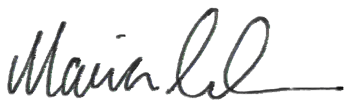
PREFACE

This thesis is the final part of my education in agricultural engineering. The purpose of this thesis has been to decrease the heat stress for high producing dairy cows in tropical climates, by creating a design proposal for a milk centre where mechanical cooling are used to cool the cows. The work has been done during the summer and autumn 2004, with AgrD Knut-Håkan Jeppsson as supervisor. Examinator of the thesis was Professor Krister Sällvik and opponent was Professor Christer Nilsson. The thesis comprises 20 weeks of work in the subject technology.

My hoping of this thesis is that it will be guidance for a possibility to develop mechanical cooling in milk centers, in order to cool the cows and their environment to avoid heat stress.

I would like to thank Mr Gert Danneker and Mr Björn Forss, DeLaval International AB, for helping me with the idea of the thesis and formulation of the problem. Also thanks to my supervisor, AgrD Knut-Håkan Jeppsson, for the support and assistance with the writing, and for answering all my questions. Finally big thanks to everybody that made this thesis possible.

Alnarp, November 2004



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NOTATIONS

A	surface area, m^2
d	thickness of a construction, m
e	enthalpy, kJ/kg
F	latent heat dissipation from animals, g/h
Fc	moisture that needs to be dehumidified, g/h
Fv	latent heat in ventilated air, g/h
H	height, m
h	heat transfer coefficient for convection and long wave radiation, W/m^2K
I	global solar irradiation against a building envelope in relation to floor area, W/m^2
k	heat transfer through building sheet, W/m^2K
M	mass flow of air, kg/s
$MDEC$	Milk Production Decline, kg/day
m	animal weight, kg
NL	normal lactation, kg/day
P	heat, W
Pc	heat that need to be cooled, W
$Pcow$	heat dissipation from cows, W
Pt	heat added through conduction, W
Ps	extra heat load from equipment, W
$Psens$	sensible heat loss from cows, W
Pv	sensible heat in ventilated air, W
p	days of pregnancy, days
q	ventilation rate, m^3/s
R	heat resistance, m^2K/W
T	temperature, °C
THI	Temperature Humidity Index
U	heat transfer coefficient through a building surface, W/m^2K
UT	overall heat transfer coefficient through a building surface, W/m^2K
v	altitude of the sun, degree above horizon
W	width, m
X	maximum water contents of air, g/kg
Y	production of milk, kg/day
α	absorptance
λ	heat conductivity for materials, W/mK
ρ	air density, kg/m^3
Φ	relative humidity, %

Subscripts

a	area exposed to solar irradiation
db	dry bulb
dp	dew point
f	floor
hor	against horizontal plane
i	inside
n	all numbers
nt	non-transparent
o	outside

SUMMARY

The increase of milk consumption in south East Asia requires an increase in milk production. Cows suffering from heat stress are a big problem for milk producers in these hot and humid countries. The consequences of heat stress for cows are declines in food consumption which leads to declines in milk production and fertility. If the cows shall be able to produce more milk, they or their surrounding environment must be cooled in some way.

The objective of this thesis was to find out the total cooling demand in a milk centre with 160 cows, 40 cows in a double 20 parlour and a holding area fitting 120 cows. Also a proposal for mechanical cooling of the milk centre should be created.

The thesis is a theoretical study where a calculation model has been made to be able to identify and quantify the different contributions of supplied heat to the milk centre. The calculations have been made representing the worst case and from that the refrigerate requirement has been established. After having the refrigerate requirement the refrigerate plant that will cool the milk centre have been dimensioned.

Climate conditions were taken from Kuala Lumpur, Malaysia, which is a low land area near the ocean. This area has been chosen to get the worst climate for milk production. The calculations were made with an outdoor temperature and relative humidity at 32 °C and 60 %, respectively. The indoor climate was set to 24 °C and 80 %, which gives a THI of 73. U-value in walls and roof was 0.5 W/m^2K and the floor had a value of 0.3 W/m^2K.

The refrigerate requirement in the milk centre was calculated to 271 kW. Almost 80 % was caused by production of heat and moisture by the cows. Heat and moisture that was brought inside the milk centre with the ventilated air caused 16 % of the refrigerate requirement. The heat gained from solar radiation caused 4 % of the refrigerate requirement and only 1 % was caused by transmission through walls and floor.

The calculations made with the calculation model showed that the number of cows in the milk centre makes a big difference to the refrigerate requirement. It also indicated that the material on the outer surface of the roof should be shiny and bright so the radiation from the sun is reflected. Furthermore, it showed the importance of controlling the ventilation rate to a minimum.

In this thesis the used technique for cooling the air in the milk centre was compressor cooling. The total power consumption was calculated to 66.2 kW. With the energy price in October 2004 in Malaysia the energy cost for cooling the milk centre during the warmest month of the year should be USD 2627 (18 389 SEK). If this energy cost is divided on the number of kilo milk that is produced in the milk center in that month the cost will end up at USD 0.003 (0.021 SEK) per kilo milk. The investment cost for the total cooling system will be in the quantity of USD 300 000 (2 100 000 SEK). Because the cows will only be cooled for two hours a day in the milk centre it is hard to say if the milk production will increase and make an investment in mechanical cooling feasible.

SAMMANFATTNING

Mjölkkonsumtionen i Sydostasien ökar vilket leder till ett behov av ökad mjölkproduktion. Ett stort problem för mjölkproducenterna i dessa länder är det varma och fuktiga klimatet som gör att korna lider av värmestress. Värmestress hos kor leder till ett minskat foderintag och således till en minskad mjölkproduktion och en lägre fertilitet. Om kornas mjölkproduktion skall kunna öka, så måste korna och deras omgivning kylas på något sätt.

Syftet med examensarbetet var att fastställa det totala kylbehovet i ett mjölkningsstall med totalt 160 kor, 40 kor i en 2x20 mjölkgrop och en samlingsfålla med 120 kor. Även ett förslag med mekanisk kylning av mjölkningsstallet skulle utarbetas.

Examensarbetet är en teoretisk studie där en beräkningsmodell har framtagits för att kunna identifiera och kvantifiera orsakerna till kylbehovet i mjölkningsstallet. För att dimensionera kylanläggningen har beräkningarna gjorts utifrån de högsta värmebelastningarna som kan uppträda.

De väderdata som har använts härrör från Kuala Lumpur, Malaysia, som ligger i ett låglandsområde nära havet. Detta område valdes för att få det värsta klimatet för mjölkproduktion. Beräkningarna gjordes med ett dimensionerande uteklimat av 32°C och en relativ fuktighet på 80 %. Det valda klimatet inne i mjölkningsstallet var 24°C och 80 % relativ fuktighet, vilket ger ett THI på 73.

Det totala kylbehovet i mjölkningsstallet beräknades till 271 kW. Utav detta stod kornas produktion av värme och fukt för cirka 80 %. Den värme och fukt som införs i mjölkningsstallet med ventilationen stod tillsammans för 16 %. Värme från solstrålning utgjorde 4 % av kylbehovet och 1 % berodde på transmission genom väggar och golv.

De beräkningar som gjordes med beräkningsmodellen visade att antalet kor i mjölkningsstallet har stor inverkan på kylbehovet. Beräkningarna visade även att materialet hos den yttre takytan skall vara ljust och blankt så att solstrålarna kan reflekteras. En annan viktig faktor för kylbehovet visade sig vara att ha en kontrollerad minimiventilation så att minsta möjliga luftutbyte sker i mjölkningsstallet.

I detta examensarbete har kompressorkylning använts som teknik för att kyla luften i mjölkningsstallet. Den dimensionerande effekten beräknades till 66,2 kW. Med energipriset i oktober 2004 i Malaysia blev den beräknade driftskostnaden för att kyla mjölkningsstallet under den varmaste månaden av året 18 389 SEK (USD 2627). Om denna månadskostnad delas upp på antalet kilo mjölk som produceras i mjölkningsstallet under samma månad så blir kylkostnaden per kilo mjölk 0,021 SEK (USD 0,003). Investeringskostnaden för den kompletta kylanläggningen är i storleksordningen 2 100 000 SEK (USD 300 000). Om inkomsten ökar till följd av att kornas produktion av mjölk ökar tack vare att de kyls två timmar om dagen i mjölkningsstallet är svårt att säga.

1 INTRODUCTION

In south East Asia climatic conditions are hot and humid and quite constant during the year (Weatherbase, 2004). One result of high environmental temperatures combined with high humidity on the cows is heat stress and heat stress significantly reduces milk production (Armstrong, 1994). Today the genetic improvements and developments in feeding technique result in larger cows that can produce more milk. Large high producing cows dissipate a lot of heat by metabolic processes and the heat production increases as the cows weight and milk production increase (West, 2003). If the ambient temperature is high enough the cow will not be able to dissipate the heat that she produces. High producing cows are therefore more vulnerable to heat and the problem with heat stress will become more acute as the production levels continue to rise. Therefore it is necessary to find effective methods to manage heat stress in order to increase milk production.

In South East Asia an increase in milk production is needed because the consumption of milk is increasing. Today milk is imported from other countries and to handle the future demand of milk the countries are interested in producing their own milk. However, the hot and humid climate in South East Asia and the fact that the countries have no tradition in milk production makes it hard to solve this problem. To increase the production of milk, breeds like Holstein and Jersey are used. Those breeds have more difficulties to handle the climate in these countries and require some type of cooling system to avoid heat stress. If the problem with heat stress can be reduced the fertility and consumption of food can increase and then the production of milk also will increase. Milk producing companies are interested in such solutions because they see an economical gain if they can increase their milk production and hence are willing to invest in a cooling system to solve these problems.

1.1 Objective

The objective of this thesis is to create a design proposal for a milk centre where mechanical cooling is used to cool the cows. The milk centre should be designed with respect to function, geometry and the quality of the materials used in the construction. The purpose is, that based on already known knowledge about the comfort zone of the cows and accessible technique for mechanical cooling and ventilation, decrease the heat stress for high producing dairy cows in tropical climates.

This thesis finds out the need of energy to cool a milk centre with 160 cows with mechanical cooling. This is done in a theoretical way by a literature review and calculations. Through the calculations the total need of energy to cool the milk centre is established. The design of the milk centre is only done with respect to floor, wall and roof areas and the materials that should be used in the constructions. The technique for the cooling equipment is not taken into consideration.

2 LITERATURE REVIEW

2.1 Heat production

Heat production is an unavoidable consequence of the metabolic processes inside the body. How the heat dissipates from the animal depends on physiology and on the surroundings with respect to air temperature, air velocity, radiation from surfaces and bedding conditions (CIGR, 2002).

Animals try to attain a constant body temperature independent of the temperature of the surroundings (Monteith & Mount, 1973). That means that the rate of heat production must be equal to the rate of heat loss. To do this the animal can loose heat in different ways showed in Figure 1. If the environmental temperature is lower than the body temperature, heat will dissipate from the animal by radiation, convection and conduction, so called sensible heat. Radiation is when heat is transported via thermal radiation from the animal to the surroundings. Radiation depends mainly on the temperature difference. Cooling by convection occurs when the layer of air next to the skin is replaced with cooler air and depends on air speed and temperature difference. Conduction appears when the animal has contact with surrounding object surfaces and heat flows from warm to cold. Conduction depends on conductivity of the object and temperature difference. Animals can also loose heat by evaporation. Evaporation occurs when sweat or moisture is evaporated from the skin or respiratory tract. These kinds of heat loss are called latent heat. This explains why dairy cattle sweat and have increased respiration rates during heat stress.

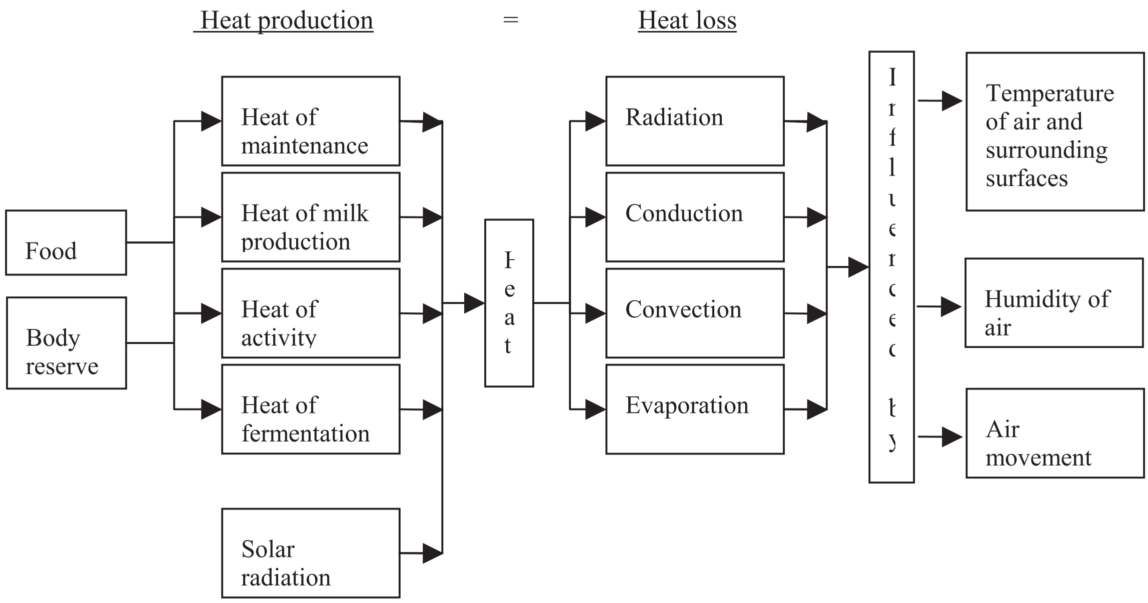

Figure 1. The rate of heat production must be equal to the rate of heat loss (after Esmay, 1978).

An animal's total heat dissipation is the sum of sensible and latent heat. When the ambient temperature rises, it reduces the possibility for the animal to loose sensible heat and the dissipation mostly depends on latent heat. The relationship between sensible and latent heat, showed in Figure 2, is affected by factors such as type of animal, production stage, body surface area, fur type, dryness of skin and sweating ability (CIGR, 2002). The area between B – E in the figure shows the temperature zone where the animal can keep a constant body temperature. With lower or higher ambient temperature, the body temperature of the animal falls or rises, respectively. Between C – E the total heat production is constant. This area is called the thermoneutral zone (Monteith & Mount, 1973). If it is provided that the animal's energy intake is distinct, this area is where the metabolic heat production of the animal is as low as possible, constant and independent of the environmental temperature. Hence, in this area the animal does not use its metabolism to control heat. The temperature boundaries of the thermoneutral zone are the lower and upper critical temperature, LCT and UCT (CIGR, 1999). LCT is well defined and refers to the temperature below which animals must adjust their metabolism to maintain body heat. This results in that those nutrients that are normally available for growth or maintenance is being changed to heat production. LCT for cattle depends on insulation provided by the hair coat, environmental factors and feed intake (Del Vecchio, 2004). UCT is the opposite of LCT. Above the UCT the animal has to increase its metabolism to cool their body. This temperature is not exactly defined and not easy to determine as it depends on many factors, both relative to the animal and to the environment (Chiappini & Christiaens, 1992). The area C – D is the comfort zone where the animal's effort to maintain body temperature is at minimum (Monteith & Mount, 1973).

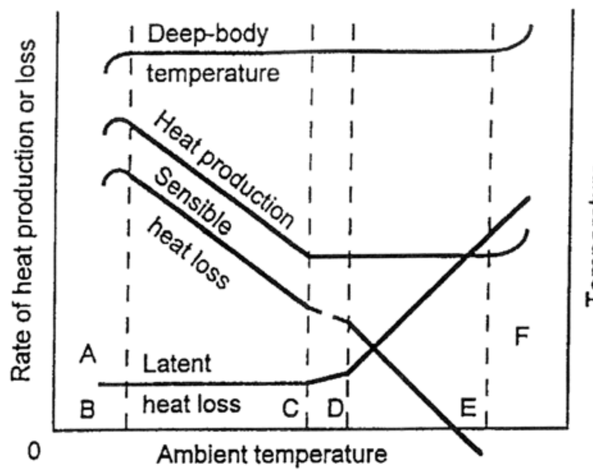

Figure 2. Schematic representation of relations between total, sensible and latent heat loss and deep-body temperature in a homeothermic animal due to environmental temperature. A: zone of hypothermia; B: temperature at maximum metabolism and beginning hypothermia; C: lower critical temperature; D: temperature of marked increase in latent heat loss; E: temperature of beginning hyperthermia; F: zone of hyperthermia; CD: comfort zone; CE: zone of minimal metabolism or thermoneutral zone; BE: thermoregulatory range. (after Monteith & Mount, 1973).

The total heat production from an animal depends on its body weight and production level. Eq (1) calculates the total heat production for one cow (Svensk Standard, 1992).

$$P_{cow} = 5{,}6m^{0{,}75} + 22Y + 1{,}6 \cdot 10^{-5} p^3 \quad (1)$$

P_{cow} = total heat dissipation per cow [W]

m = body weight [kg]

Y = production of milk [kg/day]

p = days of pregnancy [days]

2.2 The cow's requirements

The effect of the environment on the cow depends on the cow's genetically basis, the thermal environment and the production level (Sällvik, 1994). This means that different dairy breeds have different ideal environment temperatures. Hot humid weather causes heat stress. The consequences when a dairy cow gets heat stressed are declines in fertility, feed intake and milk production. Reducing heat stress can lower or eliminate these losses. Heat stress occurs when the ambient temperature lies outside the cow's thermoneutral zone (Armstrong, 1994). Four environmental factors influence the ambient temperature:

1. air temperature
2. relative humidity
3. air movement
4. radiation from the sun and surrounding surfaces in the building

Of these four factors the one with most important contribution to heat stress is increased air temperature (Buffington *et al*,. 1981). Heat stress reduces feed intake which in turn reduces milk yield. The produced quantity of milk for dairy cows generally starts to drop at temperatures above 25 °C and with relative humidity above 50 % (Chiappini & Christiaens, 1992).

THI (Temperature Humidity Index), is an index that incorporates the combined effects of temperature and relative humidity. THI is commonly used to indicate the degree of heat stress on diary cattle. For high producing dairy cows, mild heat stress occurs when THI exceeds 72. Moderate heat stress occurs when THI exceeds 80 (Armstrong, 1994). In Figure 3, the general stress levels caused by combinations of temperature and humidity on dairy cattle are shown. According to West (2003) milk yield declines by 0.2 kg per unit increase in THI when THI exceeds 72. Although THI is a useful indicator of heat stress, it does not include wind speed, the cow's weight and production level. For a more correct index those should be included, because a high producing cow is more sensitive for high temperatures than a cow with normal production. Also if there is a wind blowing it will feel colder and if the skin is wet it will feel even cooler (Armstrong, 1999).

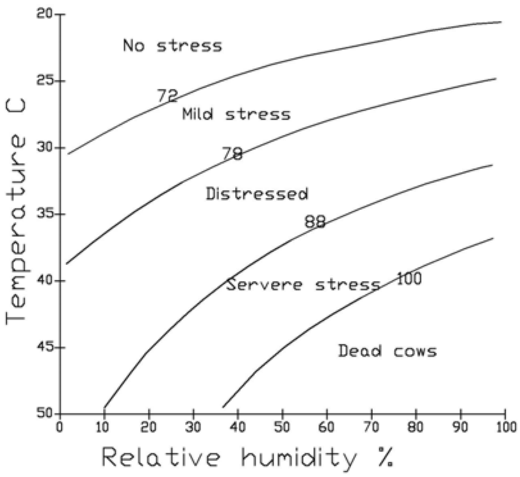

Figure 3. General stress levels at different Temperature Humidity Indexes (THI) (after Armstrong, 1993)

To calculate THI, eq (2) is used. The equation was originally developed by Thom and Bosen, United States Weather Bureau, as a comfort index for humans (Thom, 1958 and Buffington *et al*, 1981).

$$THI = T_{db} + 0{,}36T_{dp} + 41{,}2 \qquad (2)$$

THI = Temperature Humidity Index

T_{db} = dry bulb temperature [°C]

T_{dp} = dew point temperature [°C]

Dairy cow milk production decline (MDEC) can be calculated as a function of THI, see eq (3) (Hahn and McQuigg, 1967).

$$MDEC = 1{,}075 - 1{,}736(NL) + 0{,}02474(NL)(THI) \qquad (3)$$

$MDEC$ = Milk Production Decline [kg/day]

NL = normal level of milk production [kg/day]

2.3 Heat transfer in buildings

Heat and energy transfer from and into a building in different ways: transmission, radiation and change of air (Hamrin, 1996). These different ways are showed in Figure 4.

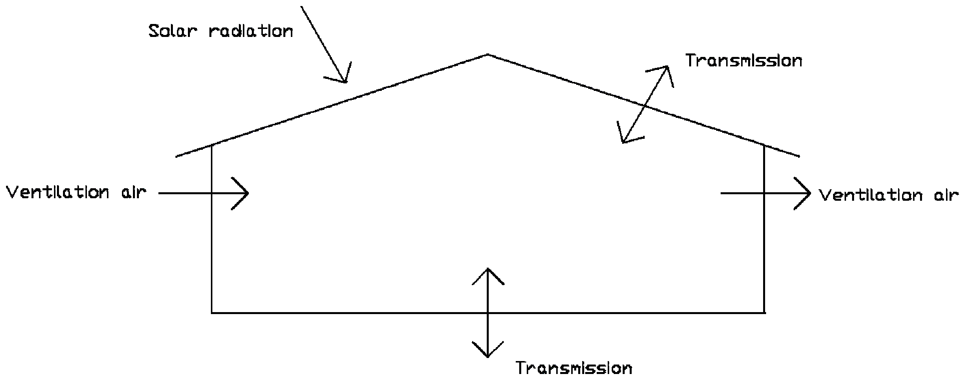

Figure 4. The three ways heat and energy transfer from and into a building.

For designing of heating or mechanical cooling systems each of these three ways are important. To calculate temperature and moisture within a closed animal shelter, the simplest way is to use steady-state conditions witch means that the building do not have any storage component. This means that the inflow of heat plus the heat that is generated in the building must equal the outflow of heat. In steady-state it is assumed that the temperatures on both sides of the building are at a constant level for a sufficient period of time, so that the heat that is leaving on one side of the building equals the heat entering on the other side. This never happens in real world, the temperatures change constantly, so the steady state concept is a simplification (CHPS, 2002). The steady state energy balance can be expressed as eq (4).

$$P_s + P_{cow} + M_1 e_1 = P_c + M_2 e_2 \qquad (4)$$

P_s = extra heat load from equipment [W]

P_{cow} = heat from cows [W]

M_1e_1 = mass of incoming air multiplied by its enthalpy per unit of mass [W]

P_t = heat conducted through the exterior surfaces of the building [W]

M_2e_2 = mass of outgoing air multiplied by its enthalpy per unit of mass [W]

(Esmay, 1978)

2.3.1 Transmission

Transmission means that heat is transferred with conduction through the building construction. According to the second law of thermodynamics, heat can only be transferred from a body with higher temperature to a body with lower temperature and never the opposite. This means, that in a building that are cooler on the inside then on the outside, heat will be conducted into the building. How much heat that will be conducted depends on how well insulated the building are, which area the construction (e.g. a wall) has and how big the temperature difference between the outside and inside is (Hamrin, 1996).

Steady state transmission

When overall heat transfer is calculated through the boundaries of the building it often involves more than one layer of material. All of these layers of materials in a construction must be taken into consideration when the heat flow is calculated. The equation for steady-state heat conduction though a building, which has solid boundaries, is shown in eq (5).

$$P = UA(T_i - T_o) \quad (5)$$

P = heat transfer [W]

U = heat transfer coefficient through a building surface [W/m^{2}K]

A = cross section area normal to direction of heat flow [m^2]

T_i-T_o = difference between inside and outside air temperature [K]

(ASHRAE, 1977)

When the insulation capacity of a building material is measured a coefficient of the heat transfer loss is used, called U-value. This coefficient indicates how much heat that is transferred from the outside to the inside through a construction for one square meter if the temperature difference is one degree (W/m^{2}K). The U-value, see eq (6), depends on the materials conductivity and the thickness of the construction, see eq (7).

$$U = \frac{1}{R} \quad (6)$$

$$R = \frac{d}{\lambda} \quad (7)$$

R = heat resistance for the materials in the construction [m^{2}K/W]

d = thickness of a construction [m]

λ = heat conductivity for materials [W/mK]

To get the U-value for the overall construction, eq (8), the total heat transfer has to be calculated. The overall U-value depends on all the different conductivities and the thicknesses of the materials in the construction, eq (9).

$$U_T = \frac{1}{R_{tot}} \quad (8)$$

$$R_{tot} = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + ... + \frac{d_n}{\lambda_n} \quad (9)$$

U_T = overall heat transfer through a construction [W/m^{2}K]

R_{tot} = total heat resistance for all the materials in the construction [m^{2}K/W]

When the overall heat transfer through all the constructions in the building is calculated, all these values will be summarized and the total energy transfer through the building has been found out, showed in eq (10).

$$P_{tot} = P_1 + P_2 + ... + P_n \quad (10)$$

P_{tot} = total heat transfer through building [W]

$P_1, P_2 ... P_n$ = heat transfer through all different constructions in the building [W]

(Hamrin, 1996)

2.3.2 Radiation

Radiation is one of the three basic mechanisms by which heat transfers from one body to another body of different temperatures. It is when electromagnetic waves carrying energy are passing through the separating medium, that thermal radiation is arising. When heat is transferred to the air volume inside the building, the size of the heat gain is affected by many factors: the absorption factor of exterior surfaces, the heat transfer loss coefficient of the building surfaces and the difference in out-, and indoor temperature (Jeppsson, 2000). The radiation heat transfer increases rapidly with increases in temperature level. So in warm and sunny days, the solar radiation is an important source of heat gain in buildings (Esmay, 1978).

There are two types of radiation, direct radiation from the sun and diffuse radiation from the sky. The later one is when the solar radiation has been scattered at least once before it reaches the surface. Diffuse sky radiation appears principally in cloudy days, but even during cloudless days a certain diffuse radiation appears. Therefore, heat will be transferred into the building from solar radiation even in cloudy days. The intensity of the radiation differs between the two types. Direct radiation can reach more than 1000 W/m^2 in intensity, while diffuse radiation has a magnitude of 50 – 100 W/m^2 (Gustafsson, 1988). The total solar radiation, also called the global radiation, is the sum of the direct radiation and the diffuse sky radiation (Duffie & Beckman, 1974).

Radiant energy that hit a surface can be absorbed, reflected or transmitted through the material. If the material is non transparent, the fraction of transmission will be zero. That means that all the radiant energy is either absorbed or reflected. The relationship between reflectance and absorption is based on the assumption that a black surface has the reflectance zero and the absorption is one. For different materials the factors for reflectance and absorption varies. To achieve minimum heat load on the building from sun radiation, the reflectance factor should be high and absorption factor should be low for the exposed areas of the materials, that is to say the upper surface of the roof. In Table 1 different absorption factors for different surfaces are listed (ASHRAE, 1977).

Table 1. Absorption factors for different surfaces (after Esmay, 1978)

Surfaces	**Absorption factor**
Metals	
Aluminum	0.32
Aluminum, polished	0.26
Copper	0.30
Copper, polished	0.18
Galvanized iron, new	0.65
Zink, polished	0.46
Galvanized steel	0.30
Paints	
White paint on aluminum	0.20
Black paint on aluminum	0.94 - 0.98
Building materials	
Asbestos cement board, white	0.59
Plaster	0.35
Bricks, red	0.55
Bricks, cream	0.40
Glass	0.92

Also the back surface of the material exposed to solar irradiation is important when choosing the roof material. The most effective back surface should have black undercoating with high absorption factor. If the back surface has a reflecting material, as it should on the upper surface, it will transfer a lot of the hot ground radiant intensity or radiosity directly to the animal (Esmay, 1978).

Heat transfer in buildings exposed to solar irradiation

Both roof and wall surfaces may be exposed to solar irradiation and this must be considered when estimating the global irradiation against a building. This can be done by relating all irradiation against the building envelope to the floor area, see eq (11) (Jeppsson, 2000). The highest rate of solar irradiation to a surface is received in direct radiation when the surface is perpendicular to the sun (Gustafsson, 1988).

$$I_f = I_{hor} + \frac{H \tan(90 - v) I_{hor}}{W} \tag{11}$$

I_f = global solar irradiation against a building envelope in relation to floor area, [W/m^2]

I_{hor} = global solar irradiation against a horizontal plane, [W/m^2]

H = wall height, [m]

W = building width, [m]

v = altitude of the sun [°]

When a building is exposed to solar irradiation the temperature of the absorbing areas rises compared to the outside air temperature. To find out the heat transfer to the building from solar irradiation, the temperature of the areas exposed to solar irradiation has to be calculated, see eq (12). The symbols and their meaning in eq (12) are showed in Figure 5.

$$T_a = \frac{(I_f \alpha \frac{A_f}{A_a} + h_o T_o + U_{a,nt} T_i)}{(h_o + U_{a,nt})} \tag{12}$$

Where $U_{a,nt}$ is the heat transfer coefficient [W/m^{2}K] downward through absorbing surfaces and expressed as eq (13)

$$U_{a,nt} = \frac{1}{\frac{1}{k_a} + \frac{1}{h_i}} \tag{13}$$

k_a = heat transfer through building sheets [W/m^{2}K]

h_i = sum of heat transfer coefficients for convection and long wave radiation for indoor surfaces [W/m^{2}K]

α = absorption factor

A_f = floor area [m^2]

A_a = area exposed to solar irradiation [m^2]

h_o = outside heat transfer coefficient for convection and long wave radiation [W/m^{2}K]

(Jeppsson, 2000)

Once having the temperature of the areas exposed to sun irradiation the heat transfer to the building can be calculated with the standard heat transmission equation, eq (5).

But instead of the outside air temperature (t_o), the temperature of the exposed areas (T_a) is used, eq (14).

$$P = UA(T_a - T_i) \qquad (14)$$

(Esmay, 1978)

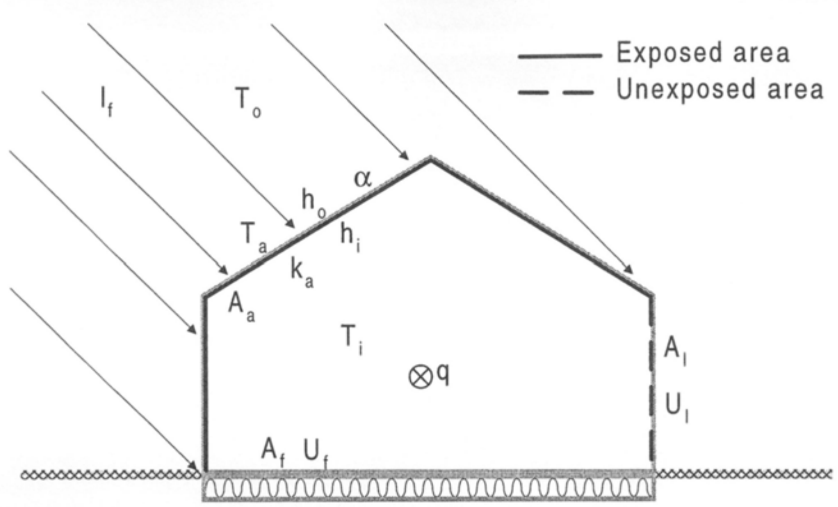

Figure 5. Heat transfer of a building exposed to solar irradiation. A_a, A_f and A_l are areas exposed to solar irradiation, of floor, and not exposed to solar irradiation, respectively; h_i and h_o are inside and outside heat transfer coefficient for convection and long wave radiation; k_a is heat transfer through building sheets; I_f is solar irradiation in relation to floor area; q the ventilation rate; T_i, T_o, and T_a are inside and outside air temperatures and temperature of areas exposed to solar irradiation; U_f and U_l are heat transfer loss coefficient of the floor and of building areas not exposed to solar irradiation; α is absorptance (Jeppsson, 2000).

2.3.3 Air Exchange

Ventilation means changing the air inside the building. If the "new" air, which is taken from outside the building, has a higher temperature than the accepted inside air temperature the building, the "new" air needs to be cooled down. The inflow of "new" warm air to the building will therefore require energy to be cooled down (Hamrin, 1996).

Ventilating systems

There are many types of ventilating systems. Regardless of the type, recommended ventilating rates are the same. Below are four examples of different ventilating systems.

- Natural ventilation is a system that depends on wind and thermal buoyancy, acting alone or together. Arrangement, location and control of ventilation openings are important to combine rather than oppose the two forces (ASHRAE, 1977).

- Negative pressure systems have exhaust fans that blow air out of the building. Then a negative pressure is created in the building and air will be drawn into the building through designed inlets.

- Positive pressure systems have fans that blow air into the building. Then a positive pressure is created in the building and air will exit the building through exhaust openings. When using a positive pressure system air distribution systems are needed in the building to reduce drafts and to provide fresh air uniformly in the building.

- Neutral pressure systems have a fan that pushes fresh air into the building while an exhaust fan pulls stale air out of the building. The two fans create a near natural pressure in the building, which reduces the effect of leaks around doors and windows.

Need of energy to cool the incoming air

The need of energy can be reduced if the ventilation rate can be reduced. The minimum rate of the air exchange depends on the animal's production of moisture and carbon dioxide. The one of these two who requires the highest ventilation rate will dimension the minimum ventilation rate needed in the building (Svensk Standard, 1992).

To calculate the need of power in W to be provided to cool the incoming air, eq (15) can be used. The equation gives the difference between the mass of the outgoing air multiplied by its enthalpy and the mass of the incoming air multiplied by its enthalpy (Esmay, 1978).

$$e_1 \cdot M_1 = e_2 \cdot M_2 \qquad (15)$$

e_1 = enthalpy of incoming air [kJ/kg]

e_2 = enthalpy of outgoing air [kJ/kg]

M_1 = mass of incoming air [kg/s]

M_2 = mass of outgoing air [kg/s]

Enthalpy

To calculate the energy loss both the change in temperature and humidity of the air must be considered. To do that the enthalpy of air is used, see eq (16). Enthalpy is the content of energy in the air [kJ/kg dry air] and depends on the temperature and the content of water in the air.

$$e = 1{,}005T + 1{,}86X \quad + 2500X \qquad (16)$$

e = enthalpy [kJ/kg dry air]

T = air temperature [°C]

X = water content [kg/kg dry air]

If the air has a temperature of 0 °C, a normal air pressure (101. 3 kPa) and is dry, the enthalpy is zero (Sällvik, 1984).

Minimum ventilation rate due to humidity

The animal's latent heat loss is affected by air humidity and air temperature. When the environmental air reaches the same temperature as the animal's body, latent heat is the only way to dissipate heat. If then the environmental air is saturated, there will be no latent heat loss (Esmay, 1978). For calculating the minimum ventilation rate for moisture balance in a building, eq (17) can be used.

$$q = \frac{F_i \cdot 100}{\Phi_i \cdot X_i - \Phi_o \cdot X_o} \cdot \frac{1}{\rho} \qquad (17)$$

q = minimum ventilation rate due to latent heat loss from the animals [m^3/h]

F_i = latent heat dissipation from animals at indoor temperature [g/h]

Φ_i = design relative humidity at indoor temperature [%]

X_i = maximum water contents of air at indoor temperature [g/kg]

Φ_o = design relative humidity at outdoor temperature [%]

X_o = maximum water contents of air at outdoor temperature [g/kg]

ρ = air density [kg/m^3]

Minimum ventilation rate due to carbon dioxide

To calculate the minimum ventilation rate due to carbon dioxide (CO_2) concentration, see eq (18), the emission of CO_2 from the animals must be known. According to CIGR (2002) the animal's CO_2 emission (l CO_2/h), eq (19), depends on the animal's total heat production. Furthermore the highest concentration of CO_2 needs to be decided. Normal concentrations in animal houses at low ventilation rates are 3000 – 4000 ppm (parts per million). In Europe the limit of CO_2 concentration in animal houses used in calculations of ventilation rate are recommended to be 3000 ppm (CIGR, 1984). The concentration in the outdoor air is also needed for the calculations and can be assumed to 330 ppm

(Svensk Standard, 1992). The recommendations of CO_2 limit for humans are 5000 ppm in Sweden (Arbetarskyddsstyrelsen, 2000). The reason for the higher level for humans is that the recommendation is based on eight hours exposure (normal workday), compared to the 24 hours exposure for the animals. Humans react with double breathing frequency at a concentration of 30 000 ppm and at 40 000 ppm the symptom is headache and drowsiness (Gustafsson, 1988). Hence, the concentrations of CO_2 that normally appear in animal houses are no risk to health. According to Pedersen (1992), the risk of too high concentration of CO_2 indoors is none.

$$q = \frac{CO_{2prod}}{CO_{2\max} - CO_{2out}} \qquad (18)$$

$$CO_{2prod} = P_{cow} \cdot 0{,}185 \qquad (19)$$

q = minimum ventilation rate due to the animal's carbon dioxide production [m^3/h]

CO_{2prod} = animal's production of carbon dioxide [l/h]

CO_{2max} = maximum concentration of carbon dioxide in the building [ppm]

CO_{2out} = 330 ppm, assumed carbon dioxide concentration outdoors

2.4 Methods to cool the cows and their environment

There are several methods available that can alleviate animal's heat stress by reducing THI by lower dry bulb temperature or the enthalpy in the ambient air. Increasing air velocity around the animals will also facilitate heat dissipation as long as the ambient temperature is below body temperature.

2.4.1 Cooling fans

Locating cooling fans in strategic locations is the first step to cool cows. If air is flowing over the animal with a velocity between two and three meters per second, it will increase convective heat loss during stressful conditions. In holding areas and free stall shelters the fans should be installed longitudinally, spaced no more than 10 times their blade diameter. The location vertically should be just high enough so they are out of reach of the cattle and do not interfere with alley scraping or bedding operations (Shearer *et al*., 1991). A different kind of fan is "high volume low speed fans", HVLS. The 7.3 meter diameter operates at a speed of 50 rpm. Air volume moved by a 7.3 meter HVLS fan ranges from 200 000 to 250 000 m^3/hour (Kammel *et al.,* 2003).

2.4.2 Evaporative cooling

Evaporative cooling uses energy from the air to evaporate water, so called adiabatic cooling. This system lowers the temperature of the air and raises the relative humidity. Therefore evaporative cooling is most effective in areas with low humidity (Bucklin *et al*., 1991).

2.4.2.1 Evaporative cooling pads and fan systems

This system requires fans, evaporative cooling pads and pumps to circulate water to the pads. A fine mist injection apparatus injects water under high pressure into a steam of air which is blown down over the cows. It is a substantial investment to install this system and it has an high running cost. This system has not been evaluated in humid countries (Shearer *et al*., 1999).

2.4.2.2 High pressure foggers

Foggers disperse very fine droplets of water which quickly evaporate and cool the surrounding air, while raising the relative humidity. A ring of fog nozzles is attached to the exhaust side of the fan and then the cooled air is blown down over the animal's body (Jones & Stallings, 1999). This system is expensive and requires a lot of maintenance and the water must be kept very clean or the fogging nozzles will plug (Worely, 1999). A fogger system is effective in areas with low humidity and is not recommended in humid climates. In an environment which is saturated with water the droplets cannot evaporate and a "steam bath" effect is created (Bucklin *et al*., 1991).

2.4.2.3 Misters

A mist droplet is larger than a fog droplet but cools air by the same principle. The animal is primarily cooled by breathing in the cooler air. This system does not work well in humid environments, because the mist droplets are too large to evaporate before they reach the floor and the bed or feed becomes wet (Shearer *et al*., 1999). Another complication with misters is that if the system does not wet the hair coat through to the skin, an insulating layer of air can be trapped between the water layer and the skin. Then the natural evaporative heat loss from the skin will be inhibited (Jones & Stallings, 1999).

2.4.3 Sprinkler and fan cooling

Sprinkling and fan cooling is a system that is widely used to cool dairy cattle because of low investment costs and high effectiveness. A sprinkling system does not cool the air. Instead large droplets wet the hair coat to the skin and cool the cow when the water evaporates. In hot humid conditions, sprinklers alone will not effectively cool cows. But if the sprinkler system is combined with forced air movement the loss of body heat will increase, by as much as a factor of three or four (Shearer *et al*., 1999). This cooling system operates at time intervals which vary with the climatic conditions. Sprinkler and fan cooling are popular in hot humid climates. It should be remembered that this system requires a large amount of water and leaves a lot of water on the floor, which can cause foot problems (Worely, 1999).

2.4.4 Exit lane sprinklers

Cows can be cooled by cow activated nozzles which deliver water when the cow exits the parlour (Verbeck *et al*., 1995). Soaking the cows to the skin as they leave the milking parlour is a system to prolong the cooling period at milking time (Bray & Bucklin, 1997). When the cows return to the free stall or corral, moisture from the wet hair coat evaporates (Armstrong, 1994). This system works best in arid climates (Verbeck *et al*., 1995).

2.4.5 Cooling ponds

In Florida cooling ponds are used to reduce the body temperature of the cows. The cows are cooled by going down in the water. Primarily ponds reduce heat loss by conduction, but during 5-10 minutes after exiting the pond a small amount of heat is lost by evaporative cooling (Shearer *et al*., 1999). The man-made pond has a continuously in-flow of water with an overflow at the end of the pool. Ponds are drained and dredged every 1-2 years (Jones & Stallings, 1999). Cooling ponds represent a much discussed method for the management of heat stress because it is associated with a high number of diseases, e.g. mastitis (Shearer *et al*., 1999).

2.4.6 Showers

When cows are showered the heat is taken away by conduction and evaporation. Heat loss through conduction only works if the water temperature is lower than the animal’s skin and only lasts the length of the shower. The evaporation heat loss lasts as long as the cow is wet, which is about ten minutes (Chiappini & Christiaens, 1992). This system requires a great amount of water that also leads to problems with wet floors (Frazzi *et al.*, 2002).

2.4.7 Tunnel ventilation

In warm weather, tunnel ventilation is an option for ventilating stall barns. Tunnel ventilation is not used in cold weather. The system provides a combination of high air exchange rates and high airflow speeds to help the cows to remove body heat by increasing the heat loss by convection (Janni, 1999). In tunnel ventilated barns large exhaust fans are placed at one end of the barn and large openings are placed in the other end. The fans will pull outside fresh air through the inlet openings. All windows, doors and other openings should be closed along the sidewalls. To provide a uniform air movement along the barn it is important that the tunnel ventilation system is properly designed (Tyson *et al.*, 1998).

2.4.8 Underground pipes

If the ground temperature is lower than the atmospheric temperature, air can be passed through underground pipes and the air can be cooled. The pipes are normally placed at a depth of 1.5 to 2 meters in the ground. In Mediterranean countries a temperature reduction of 8 – 10 °C can be expected in the hottest hours of an average summer day. The main effect of the system is to help to remove the extremes of the temperature (Chiappini & Christiaens, 1992), but it is also a way of reducing the energy consumption for cooling by using the relatively stable soil temperature (Nilsson & Kangro, 1998).

2.4.9 Roof cooling

The radiant heat load on animals can be reduced by cooling surrounding surfaces by evaporation of water. If the roof is sprinkled, the temperature of the roof can be reduced up to 28 °C by application of 1.5 liter water per hour and square meter roof area. If roof sprinkling benefit performance is unknown. Reductions in respiration rate and rectal temperatures of cows have been observed but milk production was unaffected (Dooley *et al.*, 1980).

2.4.10 Mechanical cooling

Mechanical cooling, or air condition, is generally considered too expensive in animal housing. In 1978 Esmay wrote: "Air conditioning will no doubt in the future become economical for many types of domestic animal enterprises; summer production of milk, … might be increased in many areas, and introduced in other areas where high summer temperatures have made production unsuitable". Since 1978 the refrigeration technology has improved and together with a good design and insulation of the barns, mechanical cooling in animal houses might be feasible. In a study in Florida, Bray *et al*. (2003) showed that in hot humid climates cows in barns cannot be free from heat stress without mechanical cooling. In the study a mechanical cooled barn always had a THI below 72, compared to a barn without mechanical cooling that never got a THI below 72.

To elaborate the cooling design of a building, the total heat load must be calculated. That can be done in a similar way to designing air exchange of the ventilation system for barns in cold weather. Then there are four aspects to be considered (Esmay, 1978):

1. heat transmission through surfaces that are exposed to temperature difference and solar radiation
2. heat and moisture production by the animals
3. ventilation air and air that infiltrate the building
4. supplementary heat from equipment and lights

2.5 Design of milk centre

When planning the milk centre the orientation of the building must be considered. If the milk centre is located in north-south orientation, the building is exposed to greater solar radiation than with an east-west orientation. This is because sunlight can enter north-south orientated buildings in the mornings and afternoon. In the afternoon the sun is low in the sky and therefore most detrimental. Also the heat stress of the animals is usually at its greatest magnitude in the afternoon. Shearer *et al*. (1999) says that the preferred orientation of the buildings is an east-west orientation because then a maximum amount of shade is achieved.

The wall height and eave extension of the building also need to be considered. With greater sidewall heights, more direct afternoon sun can hit the building. (Brouk *et al*., 2001). The direct irradiation on the sidewalls can be reduced with greater eave extensions. A big eave extension can provide shade to the building (Gralla Architects, 2000-2001). According to Palmer (2004), the eave extension should be one third the height of the sidewall.

The size of the holding area should be designed in relation to the size of the milking parlour, so the holding area can hold one group of cows. The cows should not be kept for more than one hour in a milk centre. When determining the size of the holding pen it should be sized to a minimum of 1.5m^2 per cow. The floor of the holding area should be sloped between 3% and 5%. The slope makes the cows facing the parlour, because cows do not like to stand downhill (Van Lieu, 2003). The holding pen can be divided into wash and drip pens. If using holding pen washing, cow cleaning in parlour can be reduced. In that case each pen should be sized to hold one group of cows (Smith *et al*., 1997).

For ventilation of the milk centre, both operator and cow comfort has to be considered. In the parlour both heat and moisture need to be removed. In both smaller and larger parlours a combination of natural and mechanical ventilation can be used. Fresh air from openings in the sidewall is forced into the parlour above the operator pit and then forced out of the parlour into the holding area. Also a tunnel ventilation system can be used to ventilate the milk centre. Air is drawn by fans through large inlets at the front of the parlour and downwards the holding area (Van Lieu, 2003).

3 METHOD

This thesis is a theoretical case study. To find out the total refrigerate requirement in the milk centre a calculation model has been made. The calculation model has been set up in accordance with the equations described in the literature review. These equations contain a lot of parameters that have been set, and in this way a certain “case” has been created. To get knowledge about the different parameters and their contribution to the total refrigerate requirement of the “case”, calculations with the model have been made. When the calculations have been made, only one parameter in the “case” has been changed at the time and all the other parameters have been held constant. In this way, the importance the set parameters in the “case” have on the total refrigerate requirement can be investigated and estimated. Each value set on the parameters in the “case” is described below.

3.1 Outdoor climate

Countries in the tropics have a very hot and humid climate. In this thesis, the calculations will be based on the weather conditions in the area around Kuala Lumpur in Malaysia. Kuala Lumpur is approximately 35 km from the coast and a low land area situated 21 meters above sea level (Weatherbase, 2004). Many farms are built in this area although the humidity is higher in the low land close to the ocean than in the mountains. Using data from this area in the calculations will probably design the milk centre for the worst area with regards to climatic conditions. Table 2 shows the weather conditions in Kuala Lumpur, Malaysia. January to April are the months that have the warmest weather constantly during a year in Kuala Lumpur. Almost every day during a year the temperature is above 29 °C, but only during eight days in the year 2003 the temperature raise above 35 °C. March was the warmest month during year 2003. The highest recorded temperature was 36 °C and the lowest 24 °C.

Table 2. Weather conditions in Kuala Lumpur, Malaysia. 21 years of record (Weatherbase, 2004; Weather Underground History, 2004)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean °C	27	27	27	28	28	27	27	27	27	27	27	27	27
Mean high °C	31	32	32	32	32	32	31	31	31	31	31	31	31
Mean low °C	22	22	23	23	23	23	23	23	23	23	23	22	23
No of days above 29°C	29	27	30	29	30	29	29	29	28	28	26	27	341
No of days above 32°C	24	21	25	22	21	13	11	13	11	8	12	6	187
No of days above 35°C	-	1	2	1	1	-	-	1	-	-	-	-	8
Mean morning relative humidity %	96	96	96	96	96	95	95	95	95	96	97	96	96
Mean evening relative humidity %	66	66	68	73	71	66	66	65	71	73	76	72	70
No of days with fog	25	22	24	23	22	18	19	18	18	20	21	24	254
Mean wind speed m/s	2.5	3.3	1.7	1.7	2.5	2.5	3.3	3.3	2.5	2.2	2.2	1.7	2.5

In Figure 6, the distribution between the numbers of hours with a certain temperature in March 2003 can be seen. The figure duration graph shows that only one hour in March 2003 had a temperature at 36 °C. 80 hours during March 2003 the temperature was above 32 °C and the temperature never dropped below 23 °C. The 80 hours above 32 °C are distributed in 26 different days. So for each of those 26 days it is only between one and four hours a day that the temperature rises above 32 °C. The time of the day when the temperature peaks is in the afternoon between 1 pm and 5 pm (Weather Underground History, 2004).

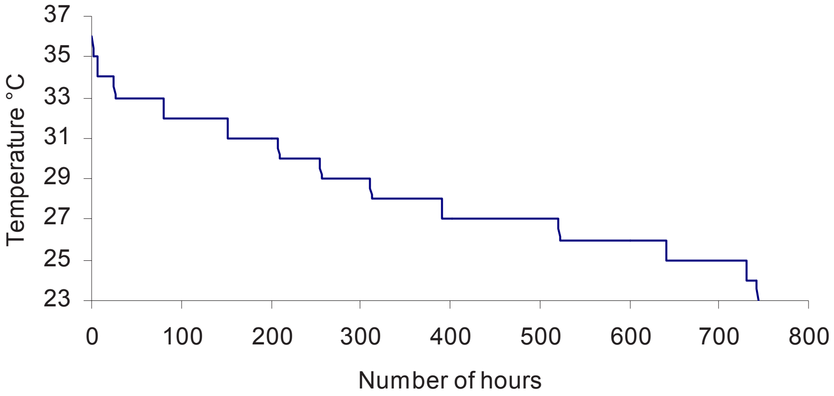

Figure 6. Duration graph, number of hours with a certain temperature during March 2003 (Weather Underground History, 2004).

When the temperature rises in the afternoon the relative humidity drops. When the temperature is 32 °C, the relative humidity is about 60 %. When the temperature peaks to 35 °C, the relative humidity drops to about 50 %. At 27 °C, which is the annual average temperature, the relative humidity is about 80 % (Weather Underground History, 2004). With reference to Table 2 the outside temperature and relative humidity have been set to 32 °C and 60 % respectively in the “case”.

3.2 Indoor climate

Which temperature and which relative humidity that should be kept in the milk centre is an important question. To find an answer, THI can be a big help. Due to Armstrong (1993), THI should be 72 or less if the cows should not be stressed at all. But at the same time the cost in energy to cool the milk centre, to keep a low THI inside, also needs to be considered. With help from Figure 3 and eq (2), the indoor temperature and relative humidity is set to 24 °C and 80 % respectively. This corresponds to a THI of 72.8. To the milk center additional heat from fluorescent tubes and machines has to be added to the heat load. In the “case” a value of 5 kW is used as a fixed sum for this extra heat load. The maximum concentration of carbon dioxide inside the milk centre is set to 5000 ppm.

3.3 Design of milk centre

The milk center’s prerequisites for the “case” are that the milk centre is designed with a holding area holding 120 cows and a milking parallel parlour with 2x20 stalls (see appendices 1,2 and 3), which gives totally 160 cows at the same time in the milk centre. Then the capacity of the parlour match the size of the holding area with four parlour turns per hour, and the cows won’t be inside the milking centre for more than one hour at a time. With these planning data the milk centre will be 13.7 meters wide and 37.4 meters long and have a floor area at 512 m^2. With a herd size of 1000 dairy cows and two milking sessions per day, the parlour will run for about 16 hours per day. The milk centre will be east-west orientated to get as low heat gain from the sun as possible.

3.3.1 The cows

To be able to calculate the sensible and latent heat production from the cows the program ANIBAL has been used (ANIBAL, 1992). For these calculations some assumptions have been made. The weight of the cows is assumed to be 650 kg. All cows are assumed to milk 25 kg/day. With these prerequisites and the chosen indoor climate, one cow’s production of latent and sensible heat is 820 W and 486 W, respectively. This gives a total heat production of 1306 W per cow.

3.3.2 Floor

Heat will be transferred through the ground and the floor into the milk centre. To calculate the value of this transmission, eq (5) has been used. A generalized U-value of 0.3 W/m^2K has been used representing the whole floor area, the whole floor construction and the heat resistance of the ground (Svensk Standard, 1992).

3.3.3 Walls

Eq (5) is also used to calculate the heat transmission through the walls into the milk centre. The walls are insulated and have a U-value of 0.5 W/m^2K. The wall height is set to 4.2 meters.

3.3.4 Roof

The outer surface temperature of the roof can be calculated using eq (12). When the surface temperature is found, the heat transmission through the roof is calculated with eq (14). Prerequisites for these calculations are that the roof of the milk centre is an insulated parallel roof with an inclination of 14°. The roof has a U-value of 0.5 W/m^2K. According to the literature review the eave extension should be one third of the wall height, which gives an eave extension of 1.4 meter. The outside material of the roof is chosen to white painted aluminum, which has an absorption factor of 0.2.

3.4 Air Exchange

The required ventilation rate in the milk centre depends on the cows' production of carbon dioxide (CO_2). Based on calculations, using eq (16) and (17), the minimum ventilation rate will be 8278 m^3/h. A positive pressure system will be used for ventilating the milk centre. A fan will blow air into the milk centre on the long side. Inside the milk centre the air will be distributed by the cooling cassettes in the roof, see appendix 2. The outlet of air will be the openings where the cows walk in- and outside the milk centre.

3.5 Solar irradiation

The prerequisites for calculations of heat gain of the milk centre due to solar irradiation are that the worst case has been assumed. According to Duffie and Beckman (1974), the highest rate of solar radiation in Malaysia is 1177 W/m^2. This rate is only reached in lunchtime and when there are no clouds in the sky. It is assumed, that it is direct radiation that hits the roof surface facing the sun. When the sun is as high as possible in the sky the solar irradiation will only hit the roof and not the walls of the milk centre. Using these prerequisites, the solar irradiation rate is calculated with eq (11).

3.6 Dimension of refrigerate plant

To find out the need of refrigerate the balance equations (20) and (21) has been used. Eq (20) gives the refrigerate requirement due to heat load and eq (21) gives the refrigerate requirement due to dehumidification.

$$P_c = P_{sens} + P_t + P_s + P_v \qquad (20)$$

$$F_c = F + F_v \qquad (21)$$

P_c = heat that needs to be cooled [W]

P_{sens} = sensible heat loss from cow [W]

P_v = sensible heat in ventilated air [W]

F = latent heat dissipation from cow [g/h]

F_c = moisture that needs to be dehumidified [g/h]

F_v = latent heat in ventilated air [g/h]

The refrigerate plant have been dimensioned in consultancy with Göran Hammarson, Alfa Laval, and Per Hannius, YORK Refrigeration AB. Despite that totally milking time is about 16 hours per day, the refrigerate plant has been dimensioned to run twenty-four hours per day.

3.7 Summary

When the calculations are made with the calculation model to find the total refrigerate requirement, equations described in the literature review are used. The values of the parameters in the used equations are summarized in Table 3.

Table 3. The set values for the case study

Case values			
Temperature outside, [°C]	32	Milk centre: Length, [m]	37.4
Relative humidity outside, [%]	60	Width, [m]	13.7
Temparature inside, [°C]	24	Height of walls, [m]	4.2
Relative humidity inside, [%]	80	Roof inclination, [°]	14
Carbon dioxide inside, [ppm]	5000	U-value: Floor, [W/m^{2}K]	0.3
Number of cows	160	Walls, [W/m^{2}K]	0.5
Milk yield, [kg/cow]	25	Roof, [W/m^{2}K]	0.5
Latent heat production, [W/cow]	820	Absorption factor of roof	0.2
Sensibel heat production, [W/cow]	486	Solar radiation, [W/m^2]	1177
Minimum ventilation, [m^3/h]	8278	Extra heat load from equipment [W]	5000

4 RESULTS

To get knowledge about and check if the set values in the “case” are the right ones before the dimensioning of the refrigerate plant; a number of calculations has been done, a kind of sensitivity analysis. Only one parameter in the calculation model has been changed at the time and the other parameters have been held constant according to the values described in methods. The results of these calculations are reported below.

4.1 Outdoor temperature and relative humidity

When calculations have been made to check the total refrigerate requirement due to different outdoor climates, the indoor temperature and relative humidity have been held constant at 24 °C and 80 % respectively. The values of outdoor temperatures and relative humidity’s that have been tested are either 27 °C and 80 %, 29 °C and 70 %, 32 °C and 60 % or 35 °C and 50 %. The result can be seen in Figure 7.

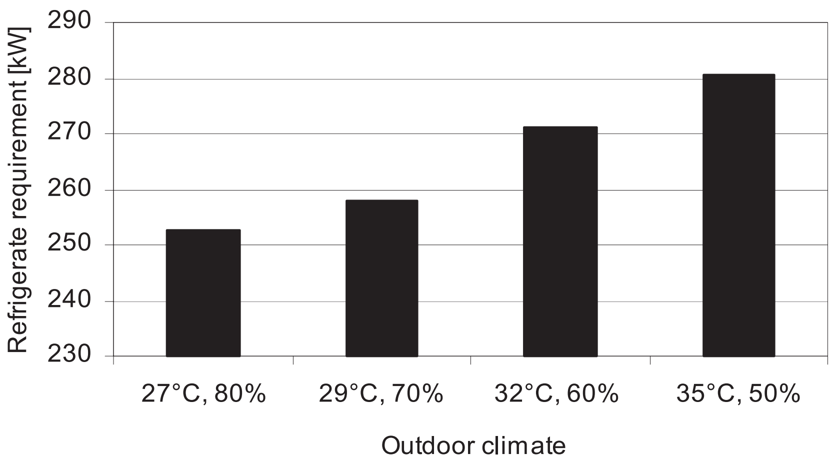

Figure 7. Refrigerate requirement due to outdoor temperature and relative humidity. Indoor temperature and relative humidity are held constant at 24 °C and 80 %, respectively.

4.2 Indoor temperature and relative humidity

A number of calculations have been made with differences in indoor temperature and relative humidity due to the total refrigerate requirement in milk centre. The outdoor temperature and relative humidity were, during the calculations, held constant at 32 °C and 60 %, respectively. The results of the calculations are shown in Table 4. Table 4 also shows the calculated THI for each combination of indoor temperature and relative humidity.

Table 4. Total refrigerate requirement and THI for different indoor temperatures and different indoor relative humidity at constant outdoor temperature and relative humidity at 32 °C and 60 % respectively

°C	23		24		25		26		27		28		29	
%	THI	kW	THI	kW	THI	KW	THI	kW	THI	kW	THI	kW	THI	kW
70	71	293	72	284	74	275	75	265	76	256	78	246	79	235
75	71	286	72	277	74	268	75	258	77	248	78	238	79	227
80	71	281	73	271	74	261	75	251	77	241	78	230	80	219
85	72	275	73	265	74	255	76	244	77	233	79	222	80	210
90	72	269	73	259	75	248	76	237	77	226	79	214	80	202
95	72	263	74	252	75	241	76	230	78	218	79	206	80	194

According to the set values in table 3, the total refrigerate requirement of the "case" will end up at 271 kW. In Figure 8, the different contributions to the refrigerate requirement and amounts respectively are shown.

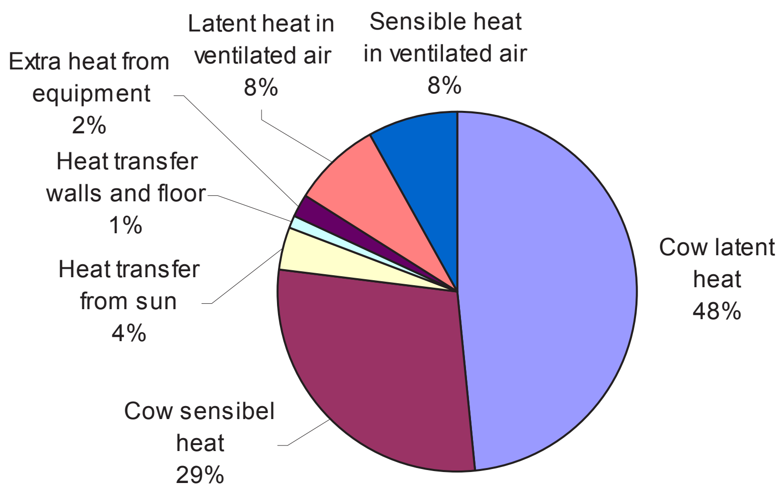

Figure 8. The different contributions to the total refrigerate requirement according to the set values in table 3.

4.3 Number of cows in milk centre

In the calculations, the size of the holding area has been design to fit either 80 or 120 cows. By having three or four batches, the holding area will be in accordance with the size of the milking parlour with 2x20 stalls. In Figure 9, the change of the total refrigeration requirement due to the number of cows in holding area is shown.

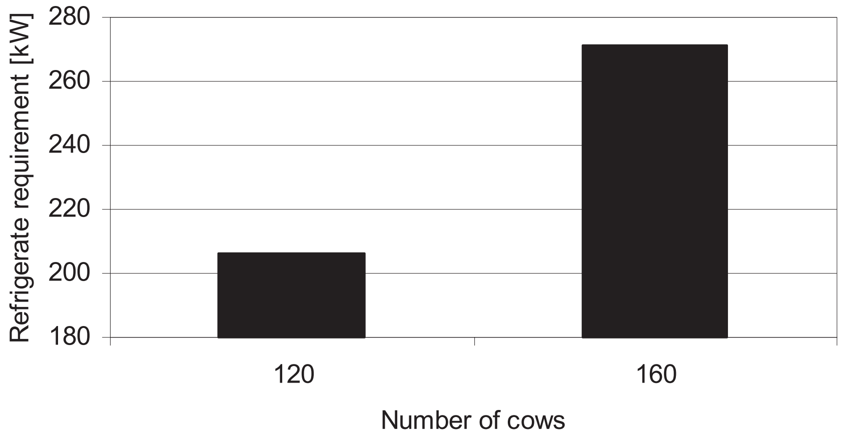

Figure 9. Refrigerate requirement due to the number of cows in the milk centre.

4.4 Milk yield of the cows

Heat production of a cow varies among other things with how much milk she produces. If a cow's milk yield rises, her heat production rises too. This will also affect the ventilation requirements and hence, the refrigerate requirement in the building. The variation of the total refrigerate requirement in the milk centre due to the cows milk yield, is shown in Figure 10. In the figure it is assumed that all cows in the milk centre have the same production of milk.

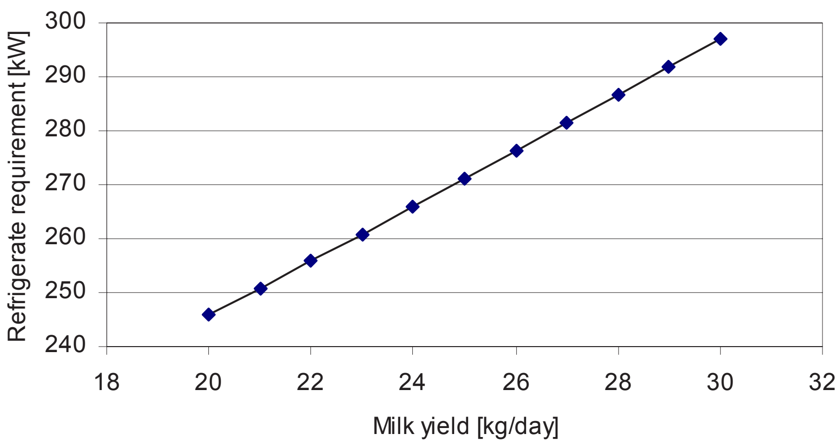

Figure 10. Refrigerate requirement due to different milk yields.

4.5 Walls

If the height of the walls is changed, the area of the building envelope also changes. When the area of the building envelope is different, the gain of heat by transmission will change. Calculations have been made where the total refrigerate requirement changes due to different heights of the walls. Tested heights of the walls are; 3.6 meters, 4.2 meters and 4.6 meters. Results of the different calculations are shown in Figure 12.

The heat gain into the building by transmission is dependent on the U-value of the walls. Calculations were made with different U-values due to the change of total refrigeration requirement. U-values from 0.4 W/m^2K to 1 W/m^2K were tested. Refrigeration requirement related to those different U-values can be seen in Figure 13.

4.6 Roof

The amount of heat transferred through the roof depends on the temperature difference between the indoor temperature and the outer surface temperature of the roof. Which temperature the outer surface of the roof gets varies with the material of the roof, because different materials have different absorption coefficients. Therefore, different roof materials were tested thus changing the total refrigerate requirement. Results of these calculations are shown in Figure 11.

Also for the roof different U-values have been tested affecting the total refrigerate requirement. Values between 0.4 W/m^2K and 1 W/m^2K were tested. Figure 14 shows results of these calculations.

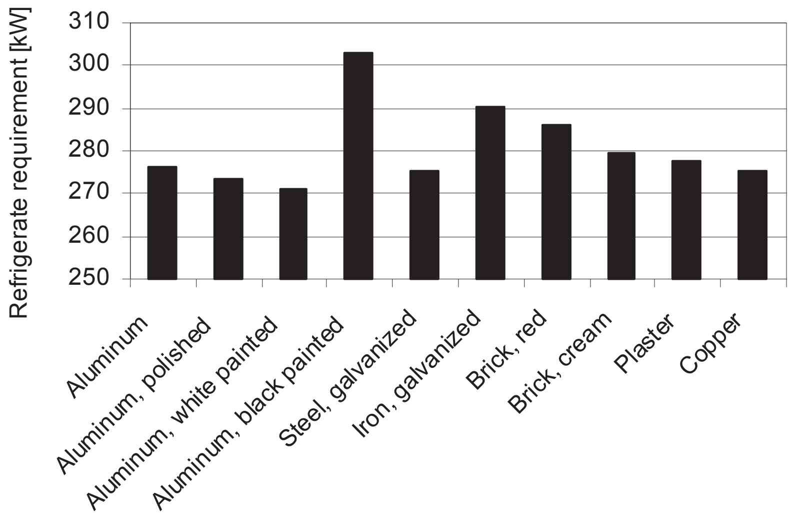

Figure 11. Refrigerate requirement due to different materials on roof surface.

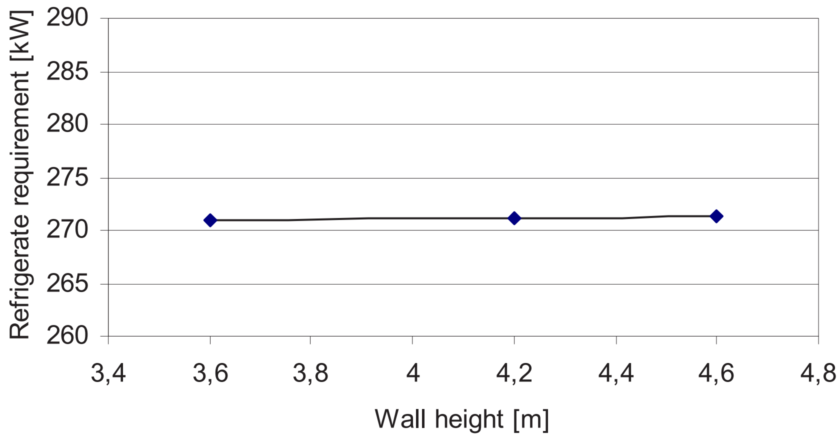

Figure 12. Refrigerate requirement due to different wall heights.

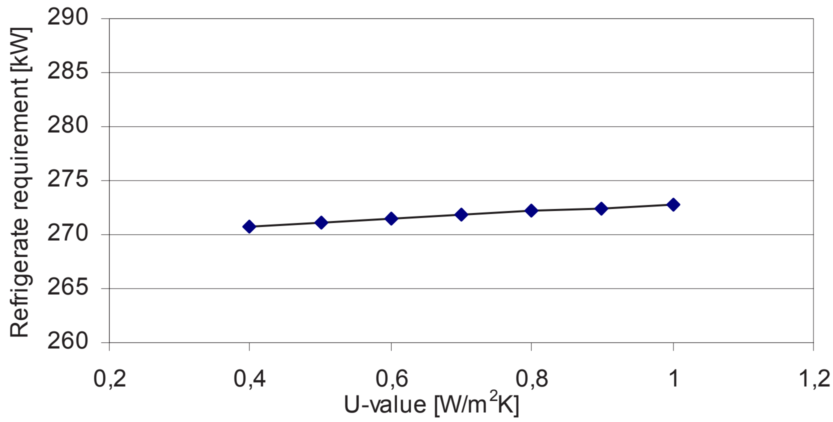

Figure 13. Refrigerate requirement due to different U-values in the walls.

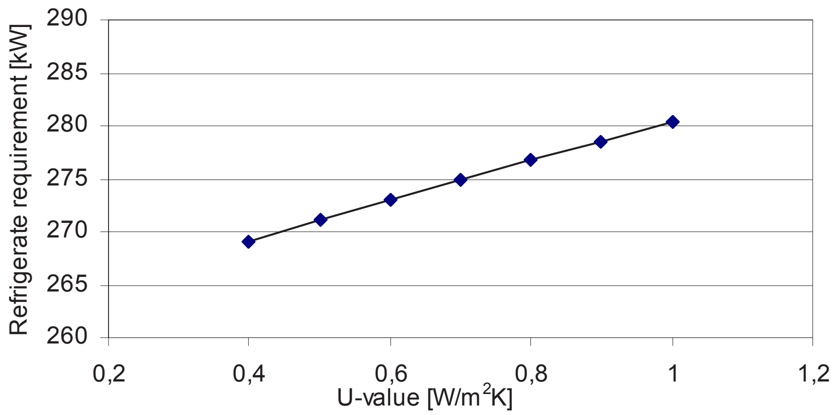

Figure 14. Refrigerate requirement due to different U-values in the roof.

4.7 Air exchange

The minimum ventilation rate in the building is calculated at 8278 m^3/h. This rate is dependent on the accepted concentration of carbon dioxide in the building. Which influence different concentrations of CO_2 have on the total refrigerated requirement have been tested and results can be seen in Figure 15.

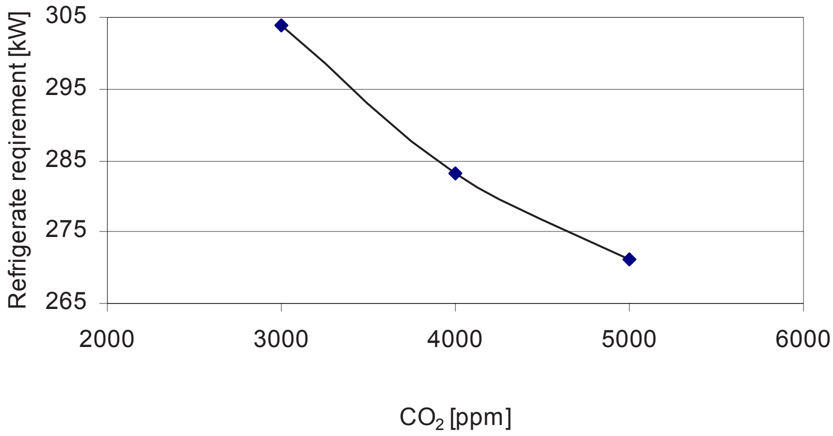

Figure 15. Refrigerate requirement due to different accepted concentration levels of CO_2.

4.8 Air coolers and refrigerate plant

The refrigerate plant will consist of one compressor; one evaporator, one condensor and five air coolers, see Figure 16. When the water returns from the air coolers in the milk centre it goes to an evaporator, where the temperature of the water will be decreased by a heat exchanger to +1 °C again, before it goes back to the air coolers. The evaporator is placed in a machine room. From the evaporator, a pipe with refrigerant goes to a compressor. The compressor increases the pressure of the refrigerant and then the refrigerant moves on to a condensing unit. The condensing unit is placed outside the milk centre and there the temperature of the refrigerant is decreased by the outside air. After that the pressure of the refrigerant is lowered by a throttle valve, and then the refrigerant returns to the evaporator.

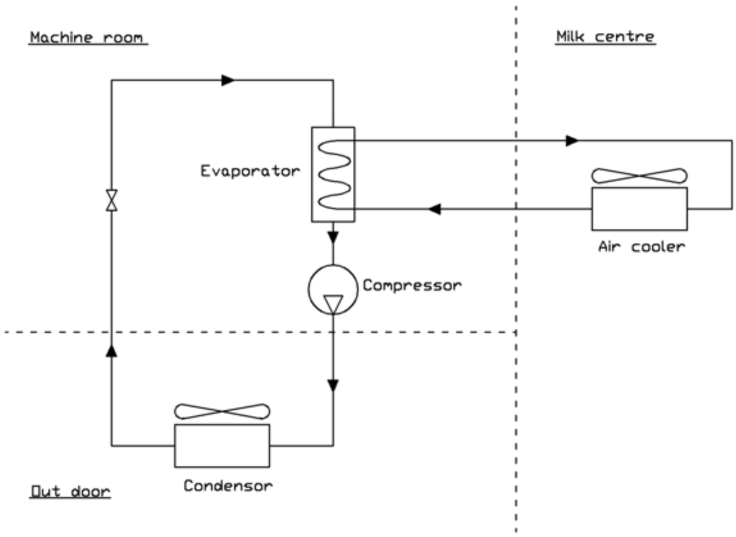

Figure 16. Principle sketch of the refrigerate plant, between the evaporator and the air cooler it is circulating water.

Inside the milk centre there will be five air coolers, Figure 17. The number of five air coolers is chosen so they can be placed at regular distances and the cooled air can easy be distributed all over the milk centre, see appendix 1. They will be hanging in the roof, so high that the cows can not reach them, but not so high that it is impossible to reach them for cleaning. The units are made of stainless steel to stand the hard environment conditions that are prevailing in a milk centre. One air cooler has four fans that press air through the unit to cool the air, and then distributes it out in the milk centre. The fans draw air from the bottom side and blow out cooled air through the long sides. Inside the air cooler the air will pass wafers that have been cooled by pipes with cold water. The water has a temperature of +1 °C when it arrives to the air coolers. A lot of water will condense in the air coolers. This condense water will flow down in coils that are placed in the bottom of the air coolers. From there the condense water will be drained to the gutter. The sound level from all five air coolers together at a distance of three meters from the units will be 57.5 dB (Hammarson, 2004).

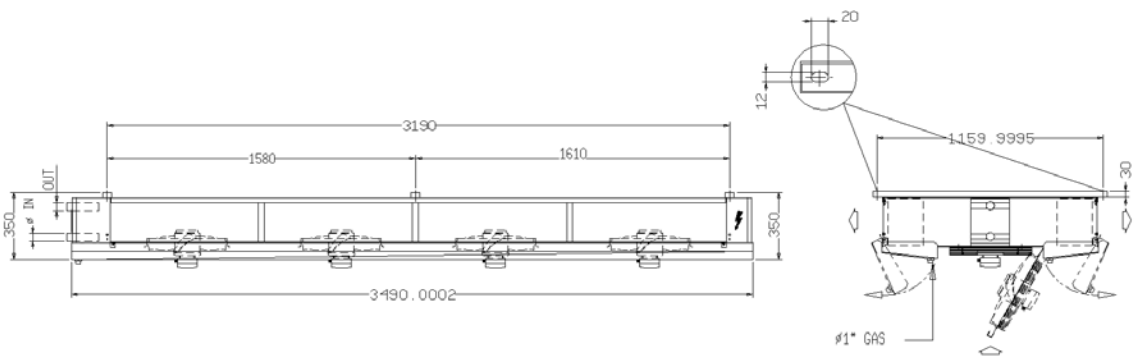

Figure 17. Sketch of air cooler, long side and cross section.

The total cooling capacity of the refrigerate plant is 274 kW. But during the warmest hour in March 2003, when the temperature reached 35 °C, the total refrigerate requirement was 302 kW. So with a maximum cooling capacity of 274 kW, the refrigerate plant is dimensioned for about 90 % of the maximum refrigerate requirement. The coefficient of performance is 4.22, so with a cooling capacity of 271 kW the total power consumption will be 64.2 kW (Hannius, 2004). When the power consumption of the air coolers are added, the sum of the total power consumption for the refrigerate plant and the air coolers will end up at 66.2 kW. In Table 5, performance data for one air cooler and for the flow of air and water passing through the air coolers are listed. With the performance data in Table 5, the performance in dehumidification for all five air coolers can be calculated to 238 kg/h. The need of dehumidification is calculated to 229 kg/h.

Table 5. Performance data for one air cooler (Hammarson, 2004)

Performance data, air cooler			
Effect per air cooler [kW]		62.06	
Power consumption [kW]		0.4	
Air		Water	
Dry bulb inlet temperature [°C]	24	Inlet temperature [°C]	1.00
Inlet relative humidity [%]	80	Outlet temperature [°C]	12.32
Dry bulb outlet temperature [°C]	13.92	Flow rate [l/s]	1.3
Outlet relative humidity [%]	97.7		
Difference in water content [g/m^3]	5.5		
Air flow rate [m^3/h]	8000		
Air velocity [m/s]	1.47		

5 DISCUSSION

5.1 Used method

The most common way today to cool cows and their environment is by evaporative cooling. The effectiveness of evaporative cooling depends on the capacity of the air to take up moisture. Consequently, in a tropical climate with high temperatures combined with high humidity, cooling with evaporative systems is limited. In those conditions, methods that are beneficial to the cow's natural mechanism of heat loss are preferable. With a mechanical cooling system the temperature in the barn can be kept down so the cow herself can emit the heat she is producing. In a mechanical cooled barn, THI can be kept around 72 and the cows can be free from heat stress (Bray *et al.*, 2003). The negative aspect of mechanical cooling is that it is expensive. Installation cost for mechanical cooling is much higher than for evaporative cooling. Also the running cost is higher, but if THI can be kept below 72 the cows should never suffer from heat stress and the effects that heat stress gives, e.g. declines in milk production. If the cows produce more milk an investment in mechanical cooling can be feasible.

In this thesis the heat transfer calculations have been made with the assumption that the heat flow is in steady state. This assumption is a simplification, because the temperature is never constant. Bur for the calculations in this thesis the steady state assumption is reasonably to do. The U-value, that is used when heat flow through constructions are calculated, gives a predictable average of heat flow rates over time. U-values are commonly used when the thermal performance of a construction is calculated and are part of the basic vocabulary of heat flow in buildings. It is a little risk that the assumption of steady state in the building can have had affected the result, but it is the general way to calculate heat transfer into and out of a building.

5.2 Outdoor temperature and relative humidity

Kuala Lumpur in Malaysia has a very hot and humid climate. Although the climate is constant during the year, the temperature in January to April is higher than the rest of the months, where March is the month with the highest temperatures.

The refrigerate plant is dimensioned for an outdoor temperature and relative humidity of 32 °C and 60 % respectively. Most time of the year the temperature is lower than 32 °C, so with a dimension regarding 32 °C the refrigerate plant will be able to handle almost the worst case. During January to April there are about 80 hours per month that has a temperature above 32 °C and those 80 hours are distributed between almost all days in the month. Therefore it is only for about one to sometimes four hours a day, during the warmest month, that the refrigerate plant will be under dimensioned. During May to December it is less then one third of all days that the temperature rises above 32 °C. If the refrigerate plant should be dimensioned for the worst case it would be able to cool the milk centre every hour of the year, but those few hours that the temperature rises above 32 °C would be very expensive to cool. To spare that extra capacity that would be needed for those few hours, the refrigerate plant is under dimensioned. But the fact that the milk centre is an insulated building will prevent heat from easily being transferred into the building by transmission. There will also be a slowness in the building envelope so hopefully, if it is only two maybe three consecutive hours that the refrigerate plant will not be able too cool the air properly, unacceptable high temperatures will not be reached inside in such a short time.

Due to the fact that when the temperature outside rises the relative humidity falls, the increasing temperature will not increase the refrigerate requirement in the milk centre so much, which is showed in Figure 7. How sensitive the indoor climate is when the outdoor temperature rises have been analysed. If the worst case of outdoor climate is assumed, which is 35 °C and 50 % relative humidity, the indoor temperature will only rise to 25 °C when still having a relative humidity of 80 %. This is no disaster for only being at the most for four hours a day and a few days a year.

5.3 Indoor temperature and relative humidity

The chosen indoor climate is 24 °C and 80 % relative humidity and it corresponds to a THI of 73. THI has been taken in consideration for this choice. The critical THI for milk production is 72. Yet it has to be remembered that a THI at 72 is not a threshold value. Around a THI at 72 the milk production usually declines but it differs depending on e.g. the local environment. If it is calm around the cow she will not be able to dissipate as much heat as she would as if the air was moving around her. So with the same temperature and relative humidity the experience of the environment differs from case to case. Although keeping THI around 72 is a good aiming point. In this case, air with a temperature around 14 °C is blown out over the cows with a 1.47 m/s velocity. So even though THI is calculated to 73 in the milk centre, the cows' experience of the surrounding air will probably be as it would with a lower value of THI.

Table 4 shows THI and the refrigerate requirement for different indoor temperatures and relative humidity's, while outdoor climate is kept constant at 32 °C and 60 %. When the temperature is constant and the humidity increase, the value of THI will increase. This happens because THI depends on both dry- and wet bulb temperature. Also the refrigerate requirement increases when the humidity increases. It is shown that it takes a lot of energy is required to cool moisture out of the air and looking at Figure 8, it can be seen that 57 % of the total refrigerate requirement is caused by drying air.

5.4 Number of cows in milk centre

In the calculations the total refrigerate requirement due to 160 or 120 cows in the milk centre were tested. Those 120 or 160 cows are the maximum amount of cows that should be held in milk centre at the same time. This will only happen during the first batch is being milked. After that it will be less and less cows as more batches are being milked. Using 120 or 160 cows in the calculations the refrigerate requirement for the worst case will be found. Cows should not be inside the milk centre for longer then one hour. With milk out time at 12 to 15 minutes, it will be around four parlour turns per hour. A 2x20 parlour takes 40 cows per turn and with four turns per hour the maximum number of cows will be 160. Also if the number of cows should be less than 120, it could be hard to plan the flow of cows so the milk centre not should be empty.

Figure 9 shows that when having either 120 or 160 cows in the milk centre the refrigerate requirement differs 65 kW, which is almost one fourth of the total refrigerate requirement. This is a big difference. But when looking at Figure 8, it is shown that 77 % of the total refrigerate requirement is caused by heat and moisture produced by the cows, so it is not that strange that the number of cows in milk centre at the same time have a large infection on the refrigerate requirement. It is clear that it would be much cheaper to plan the milk centre for 120 cows instead of 160. But, there are some things that contradict a milk centre with a maximum of 120 cows. At first it could be hard to plan the flow of cows to the milk centre. If the holding area only holds 80 cows it will be empty every 30 minutes. Then the cows can not be held far away from milk centre if they should be picked up and urged to milk centre within 30 minutes. Even if it is possible to fill the milk centre every half hour, the anti stress and cooling effect that this milk centre should have on the cows may not be so efficient when the cows are inside milk centre for only 45 minutes instead of one hour.

5.5 Milk yield of the cows

Of course the calculation of how the milk yield of the cows affected the total refrigerate requirement showed that high producing cows dissipate a lot of heat and the more they milk the more heat they dissipate. Figure 10 shows that from a milk yield of 20 kg/day per cow to a milk yield of 30 kg/day per cow, the total refrigerate requirement increased by approximately 50 kW. It corresponds to a rise of the total refrigerate requirement with roughly one fifth. With this result it seems as a milk yield of 20 kg/day should be preferred, but there is also another approach to this. The only parameter that changes in the calculations with a higher milk yield is the cow's production of sensible and latent heat. E.g. the size of the house is the same which milk yields ever, so the gain of heat due to transmission and solar irradiation will still be the same. Therefore the power consumption per kilo milk produced in milk centre is more interesting in the matter of economics. In Figure 18 the quantity of milk produced by all cows in milk centre in one hour due to the energy consumption to cool the milk centre are plotted. It clearly shows that it is more profitable to have a higher milk yield, although the refrigerate requirement will rise.

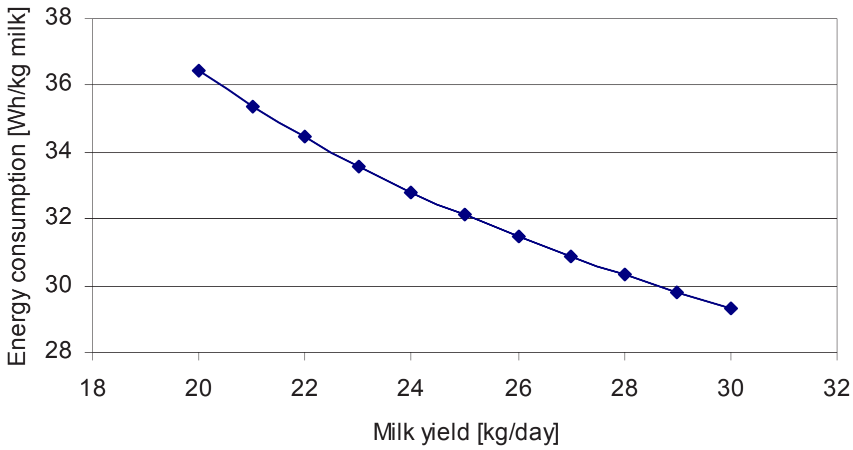

Figure 18. Energy consumption per kilo milk for the refrigerate plant due to different milk yields.

5.6 Walls, roof and floor

As shown in Figure 12 the wall height has almost no effect on the refrigerate requirement. This is explained by Figure 8 that shows that the contribution of transmission in walls, roof and floor corresponds to about 1 % of the total refrigerate requirement. So the area of the walls is not an important factor when designing the milk centre.

Figure 12, Figure 13 and Figure 14, which concern the wall height and the U-value in walls and roof, has the same scale on the y-axis so they can easily be compared with each other. The figures show that the wall height and the U-value have a small effect on the total refrigerate requirement. For walls a range in U-value from 0.4 W/m^2K to 1 W/m^2K were tested and the change in refrigerate requirement was less than 3 kW. The reason for this low change has the same explanation as the wall height, which is that the contribution from transmission to the total refrigerate requirement is small in relation to the other contributions. The U-value of the roof has a little more effect to the refrigerate requirement. In a range from 0.4 to 1 W/m^2K the change in refrigerate requirement is about 10 kW. But it is still not a big part of the total refrigerate requirement. This indicates that not so much money should be spent on insulation.

One suggestion is that instead of insulated walls, air tight curtains could be an alternative. Then in the days that are not that hot the walls could be hoisted up and the air can blow through and cool the milk centre. In the hot days, the walls should be hoisted down so the milk centre gets air tight and the refrigerate plant can be started. To do calculations on the total refrigerate requirement having curtain walls, a U-value of 3 W/m^2K can be used. If the same assumption is made that the sun is as high in the sky as possible, the total refrigerate requirement will end up at 280 kW, which is only 9 kW more than with insulated walls. But the slowness effect the insulated walls have will not be the same at all with curtain walls. Also if curtain walls should be used, they should be carefully kept in repair. Because if one curtain should be torn or broken, the milk centre would no longer be an air tight building and then the refrigerate requirement would be much higher.

When the calculation of the heat transmission through the floor were made a general U-value of 0.3 W/m^2K was used. Often when calculations of heat flow through floors are made, the transferred heat through the floor is insignificant. In this calculation the gain of heat in the milk centre by transmission through the floor is about 1.2 kW. This gain of heat is almost insignificant, so therefore a general U-value of the floor can be used. That is why no calculation on the change in refrigerate requirement depending on the different U-values on the floor has been made.

That the material on the outside surface of the roof makes a difference to the refrigerate requirement can be seen in Figure 11. The figure shows, that if a black aluminium roof is chosen instead of a white aluminium roof, the refrigerate requirement increases about 30 kW. It is clear that the material's surface should be shiny and bright to keep the refrigerate requirement as low as possible. If so, the irradiation from the sun can be reflected and there will be less heat gained through the roof. The negative aspect by having a shiny and bright roof is that the building becomes very obvious and characteristic in the surrounding environment. It will not fit in naturally in the landscape and can be seen at long distances. Also the appearance of the building becomes strange. Dark roofs posses a quality that they "binds" the building to the ground. With a bright roof the building looks like it is "floating" in the air. Probably this is because the eye gets confused when the colour of the roof looks almost like the sky.

5.7 Air Exchange

The ventilating system in the milk centre is of positive pressure type. One advantage of using positive pressured ventilation is that the inlet of air is well controlled. This is important when 16 % of the total refrigerate requirement origins from the warm and moist air that ventilation brings into the milk centre. The disadvantage with positive pressure system is the risk of pressing moist air into the building construction. But this can be decreased by putting a moist barrier in the wall. The rate of the ventilation in milk centre that is calculated is the minimum rate. If the ventilation should have a higher rate, more warm and moist air would be brought into the milk centre and a higher refrigerate requirement would be achieved. Due to that the ventilation rate is calculated with the maximum amount of cows inside milk centre, the rate only need to be that high for about one fourth of the time. The rest of the time there will be fewer cows in milk centre and a smaller ventilation rate is needed.

The govern factor for the rate of the ventilation is the carbon dioxide (CO_2) concentration inside the milk centre. Figure 15 shows the change in refrigerate requirement due to either 3000 ppm or 5000 ppm in concentration level of CO_2. If a concentration of 3000 ppm should be chosen instead of 5000 ppm, the refrigerate requirement would increase with 33 kW. This increase corresponds to 12 % of the total requirement, which is quite large. CO_2 concentration inside the milk centre is therefore set to 5000 ppm, despite that CIGR (1984) standard say it should be 3000 ppm. Different investigations have been read and there is no one that can say that a CO_2 concentration of 5000 ppm should be negative in any way, neither to humans nor to the cows. It is often suggested that an appropriate general guideline for atmospheric contaminants for housed animals is the occupational health standards for humans. Regarding concentration of CO_2 this value is 5000 ppm for a normal eight hour workday, 40 hours a week (American Conference of Governmental Industrial Hygienists, 1984). Nielsen (1984), says that at a concentration of 10 000 ppm, humans react with an increase of respiratory with 14%. Gustafsson (1988) says that, at a concentration of 30 000 ppm, humans react with double respiratory frequency and at 40 000 ppm drowsiness and head ache appear. Regarding the animals, no research results have been found on how they react at different levels of CO_2 concentration. But according to Pedersen (1992), there is no risk of too high concentration of CO_2 indoor a barn or a milk centre with normal ventilation.

CO_2 is produced by the cows and when there are fewer cows than maximum in the milk centre the concentration of CO_2 will drop. When the CO_2 concentration drops, the required ventilation rate decreases. When the ventilation rate decreases, the CO_2 concentration raises, and then it starts over again. Therefore, a good idea would be to have a sensor which can measure the concentration of CO_2 placed inside the milk centre. The task of the sensor would be to control the rate of the ventilation due to the concentration of CO_2 in milk centre. If the sensor signifies that the CO_2 concentration is lower than maximum allowed, which it will be with fewer cows in the milk centre, it will send a signal to the control unit of the ventilation and automatically the ventilation rate will be lowered by adjustment of the inlet fan. So with help from the sensor the ventilation rate should be adjusted so the concentration of CO_2 should always be at 5000 ppm in the milk centre.

5.8 Refrigerate plant

The total refrigerate requirement ended up at 271 kW. With a coefficient of performance at 4.22 a total effect of 64.2 kW is needed. If the needed effect of the fans, which is 0.4 kW per air cooler, is added to required effect of the refrigerate plant, the total effect needed will be 66.2 kW. As a comparison, a quite big fan for hay drying requires an effect of 30 kW and a refrigerate plant that are used for cooling halls with ice skating requires an effect of 750 kW.

The total investment cost for a complete refrigerate plant with the five air coolers and all the required pipes will be in the order of USD 300 000 (2 100 000 SEK). This cost is including all costs for installation of pipes and electricity, the work that is required for the installation, alarm, ventilation, a control unit for the management and help to get the refrigerate plant running. The running cost to cool the milk centre depends on the energy consumption of the refrigerate plant. The refrigerate plants power consumption will be at maximum when the outdoor temperature is 32 °C or higher. With lower outdoor temperatures the power consumption is less. In Figure 19 the number of hours in March 2003, which would have required a certain power consumption of the refrigerate plant, is shown. The area under the graph in Figure 19 would be the refrigerate plants total energy consumption in kWh during March 2003.

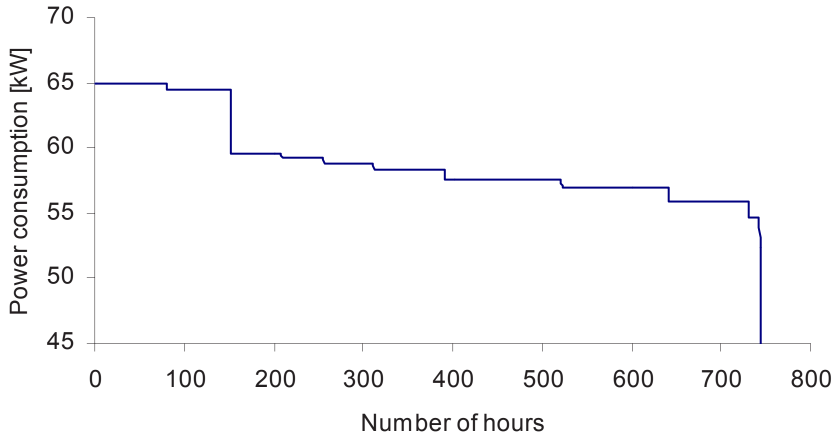

Figure 19. Number of hours in March 2003 which would have given a certain calculated power consumption of the refrigerate plant.

The electricity price for industrial companies in Malaysia is USD 0.05 (0.35 SEK) per kWh. Also a fee of USD 4.61 (32.3 SEK) per month for each kW of maximum demand is charged (Tenaga Nasional Berhad, 2004). With a calculated energy consumption that would have been required during March 2003, of 43 956 kWh, and the highest required kW at 66.2 kW, the energy cost would be USD 2627 (18 389 SEK). That is USD 0.003 (0.021 SEK) per kilo milk produced in the milk centre during March 2003. If this result of calculated power consumption and energy cost are compared to the result the study of the air conditioned barn in Florida that were mentioned before had, it shows that they are quite similar. The refrigerate plant in the barn in Florida had a total cooling capacity of 440 kW, which is almost twice as much as the milk centre in this thesis. The energy consumption in the Florida barn was about 90 000 kWh per month, and it had a monthly utility bill of USD 5400 during the summer month (Bray *et al.,* 2003). Both of these are also about twice as much as the results gotten in this thesis.

5.9 Feasible or not

An energy cost of USD 0.003 per kilo milk is not really much but no business man wants extra costs if it not is feasible. So if the milk producing companies should invest in mechanical cooling in the milk centre, they must cover the cost with a higher income. It can be read in the literature review that high environmental temperatures and high humidity causes heat stress and that heat stress can result in catastrophic losses in dairy production, such as declines in fertility and milk production. These declines can reduced when the problem with high temperatures and humidity can be ameliorated with mechanical cooling. To get a realistic value of the increase in feasibility in this case where the cows are cooled two hours a day in the milk centre is hard. One way to estimate if cooling the cows for two hours has an effect on the cow's production on milk, is to use eq (3) to calculate milk production decline for two cases. One case with no cooling in the milk centre and one case with mechanical cooling in the milk centre. These calculations showed that each cow will milk about 0.5 kg/day more if they are cooled in the milk centre. With the Malaysian milk price of USD 0.34 per kilo milk (2.40 SEK/kg) (Blomberg, 2004), the income from the extra milk that is produced will be USD 51 850 per year (366 000 SEK/year). In this calculation it is assumed that all cost for getting a higher milk production, e.g. feed costs, is constant.

In table 6, all the costs are summarized and compared to the extra income from the higher production of milk to see if an investment in a mechanical cooled milk centre will be feasible. The refrigerate plant has a depreciation of 20 years (Hannius, 2004), and the interest is 6 %.

Table 6. The extra income compared to the costs

Income compared to costs per year		
Income from higher production of milk	+ USD 51 850	+ 366 000 SEK
Depreciation, 20 years	- USD 15 000	- 105 000 SEK
Interest cost, 6 %	- USD 9 000	- 63 000 SEK
Energy cost	- USD 25 700	- 179 900 SEK
Netto	**+ USD 2 150**	**+ 15 050 SEK**

Due to these calculations, an investment in a refrigerate plant to cool the milk centre would give an extra income of USD 2 150 (15 050 SEK) per year. But in this calculation the cost for maintenance is not included, however with a realistic figure of 4 % on investment there will be a negative netto on the investment. So an investment will probably not give that extra income. If a higher income should be guaranteed, a solution which cools the cows for the rest of the 22 hours should be considered. Still, it has to be remembered that there can be other positive gains with the investment. Hopefully the cow’s fertility can increase, which will result in reduced costs. Cooling the cows for two hours per day will maybe not increase their production of milk that much, but those two hours in the milk centre is the most stressful time of the day for the cows. If the cows already are heat stressed when they arrive to the milk centre, they may not be able to handle one hour stuffed together in a place where a lot of heat are produced. But if the air in the milk centre can be cooled, the milk centre will be a positive place for the cows where they will not feel heat stressed. This can help them to manage the strains that they are exposed to during milking time.

6 CONCLUSIONS

The total refrigerate requirement ended up at 271 kW. The calculations showed, that heat and moisture produced by the cows responds to 77 % of the total refrigerate requirement. Heat and moisture that was brought inside the milk centre with the ventilated air caused 16 % of the refrigerate requirement. The ventilation rate was depended on the permitted carbon dioxide (CO_2) concentration inside the milk centre. It will therefore be important to keep the CO_2 concentration at maximum allowed (5000 ppm), which will keep the ventilation rate as low as possible. The wall height of the building and the U-value of the walls and the floor had almost no effect on the refrigerate requirement. The roof on the milk centre should be shiny and bright so that heat transferred from solar radiation will be as low as possible.

The refrigerate plant was dimensioned to keep a THI of 73 inside the milk centre. When the temperature outside is 32 °C or below, the refrigerate plant will be able to do that, which it is around 90 % of the time the warmest month of the year. If the milk centre should be build, five air coolers would be hanged from the roof in the milk centre. The units would take air from inside the milk centre and cool it. Then the units would distribute the cooled air in the milk centre. Total power consumption of the refrigerate plant would be 66.2 kW. With the energy price in Malaysia October 2004, the energy cost for the warmest month of the year would be USD 2627 (18 389 SEK). This corresponds to around USD 0.003 (0.021 SEK) per kilo milk that is produced that month. Total investment cost of the refrigerate plant would be around USD 300 000 (2 100 000 SEK).

It is hard to say if an investment in mechanical cooling in a milk centre would be feasible. But if cooling the milk centre would result in that each cow would increase her production with 0.5 kg/day, the extra income from that increased production of milk would be USD 2 150 (15 050 SEK) per year. In that case, an investment in mechanical cooling would be feasible.

7 FURTHER RESEARCH

This thesis has just considered cooling of the milk centre where the cows only will be for two hours per day. If two hours of cooling will increase the production of milk and the fertility is uncertain. That makes it hard to say if the investment is feasible or not. To be able to do so a study of a solution where the cows are cooled 24 hours a day should be made. But of course a practical study would be the best way to tell the truth.

In this thesis the power consumption to cool the air in a milk centre with 160 cows has been established after that the refrigerate requirement was found. The system used to cool the air in this research is compressor cooling. This is a quite expensive way of cooling where mechanical energy is provided by work of the compressor. If another alternative to get energy to cool the air can be found maybe a cheaper solution of cooling the milk centre can be made.

One alternative could be to use the process of absorption. In the process of absorption cold is produced by supplying energy from heat. This system is quite complicated compared to the compressor cooling system and therefore the system is not so often used. An idea is that the heat that needs to be supplied in the system can be taken from solar energy e.g. by having sun collectors.

Another alternative could be to cool the incoming air to the milk centre by taking it through underground pipes. In that system the cooling energy comes from the soil and can be sustained as long as the soil temperature is lower than the daily average temperature (Nilsson & Kangro, 1998). Researches of using the pipes in the ground for cooling the incoming air to a building have been made at Swedish University of Agricultural Science by Nilsson and Kangro (1998). The result was that the incoming air was taken in a 21 meter long pipe, 3.45 – 3.85 meter below the ground level, with an air flow rate at 500 m^3/h. The incoming air was kept below 19 °C when the outside temperature was below 30 °C. Although it has to be considered that the outer climate in Malaysia is much warmer than in Sweden so probably the soil temperature is higher in Malaysia. With a higher soil temperature the cooling energy from the soil will not be that good and the cooling effect of the incoming air will be less with a lower soil temperature. But maybe some of the energy consumption can be reduced by using underground pipes to cool the incoming air.

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8.3 Personal notifications

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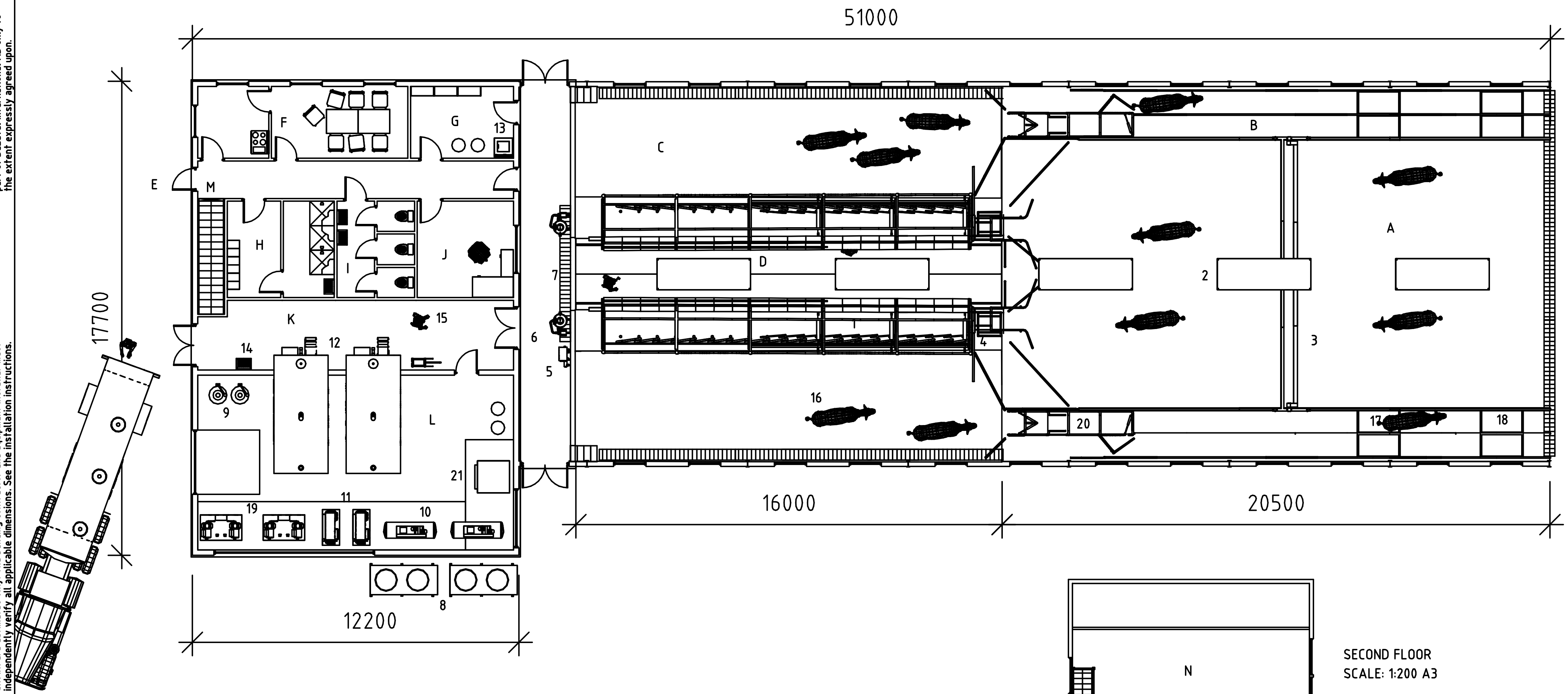
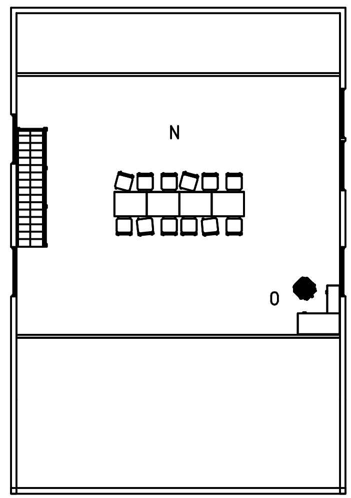
Hannius, Per. YORK Refrigeration AB. 2004

9 APPENDICES





SECOND FLOOR
SCALE: 1:200 A3

LEGEND

A. Holding area
B. Return alley
C. Cow platform
D. Operators pit
E. Entrance
F. Resting area for workers
G. Storage
H. Lockers and showers
I. Toilets
J. Herdsmans office
K. Milk room
L. Machine room
M. Stair to second floor
N. Lounge/visitors area
O. Managers office

1. Parallel parlour 2x20
2. Air cooler
3. Crowd gate
4. Identification unit
5. Cleaning unit
6. Receiver
7. Drainage gutter
8. Condensing units
9. Water heater
10. Air compressor
11. Vacuum pump
12. Milk tank 2x9700 liter
13. Washing machine
14. Sink

15. Person
16. Cow
17. Foot wash
18. Foot bath
19. Pump module Yukon Snap system
20. Sorting gate
21 Evaporator

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1000 COW DAIRY FARM MALAYSIA
MILK CENTER 2x20 PARALLEL PARLOUR
PLAN

DRAWN/DEPT.	CHECKED/DEPT.	PROJECT NO./DRAWING NO.	REV
M CARLSSON	CS-PM		A

DATE 2004-12-18
APPROVED/DEPT
SCALE 1:150; 1:200 A3

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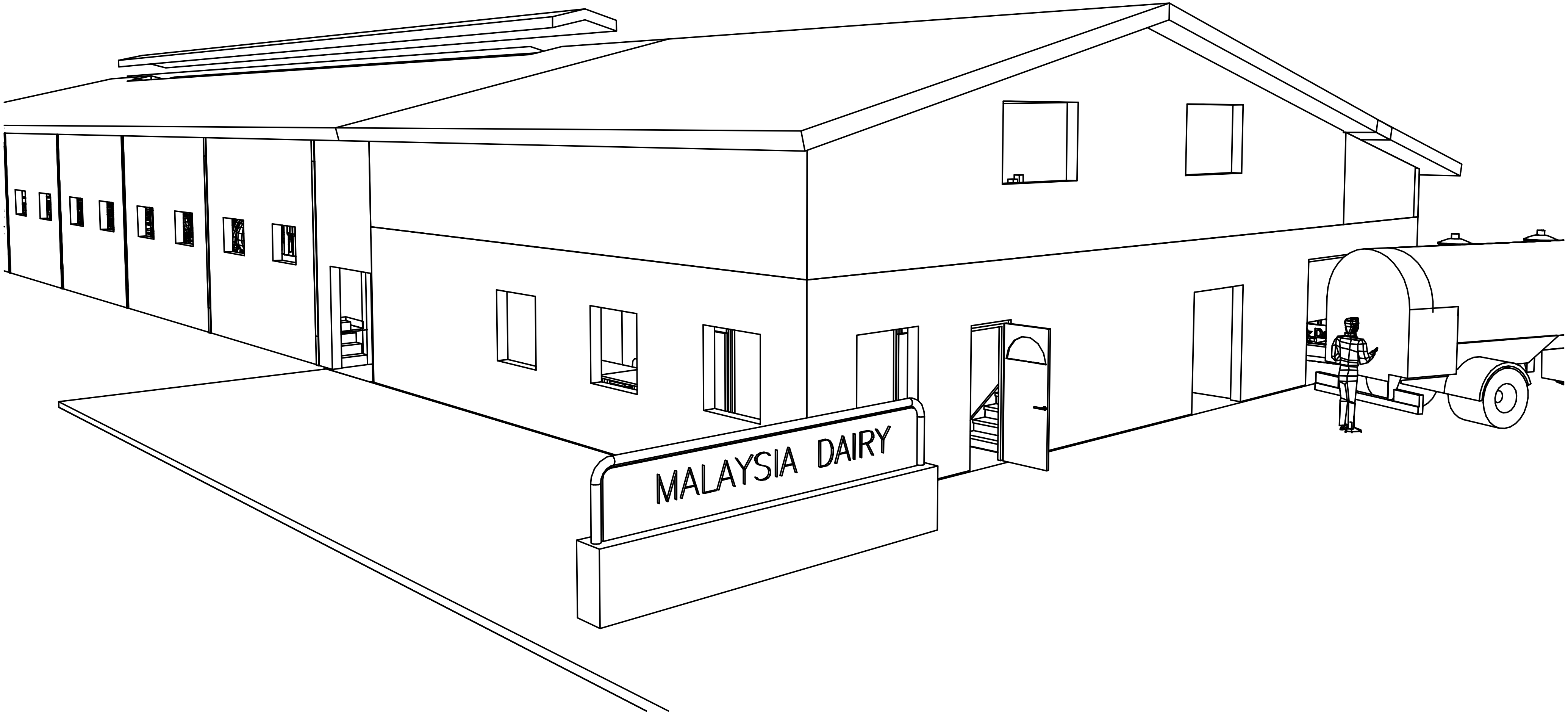

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1000 COW DAIRY FARM MALAYSIA
MILK CENTER 2x20 PARALLEL PARLOUR
OUTSIDE VIEW

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2005-01-03		NO SCALE

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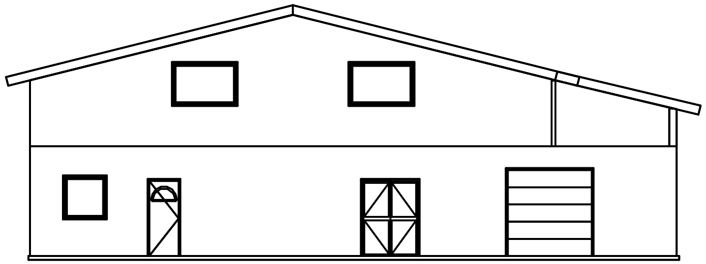

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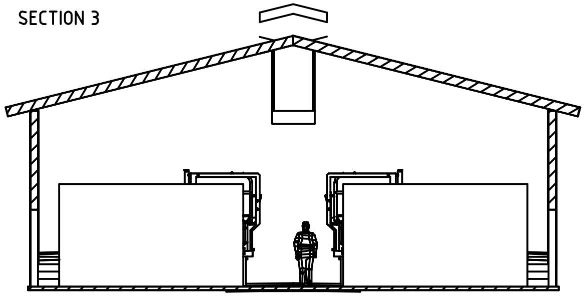

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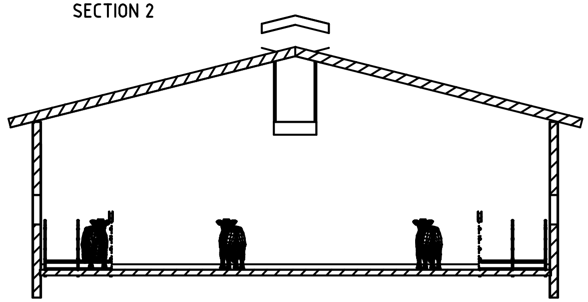

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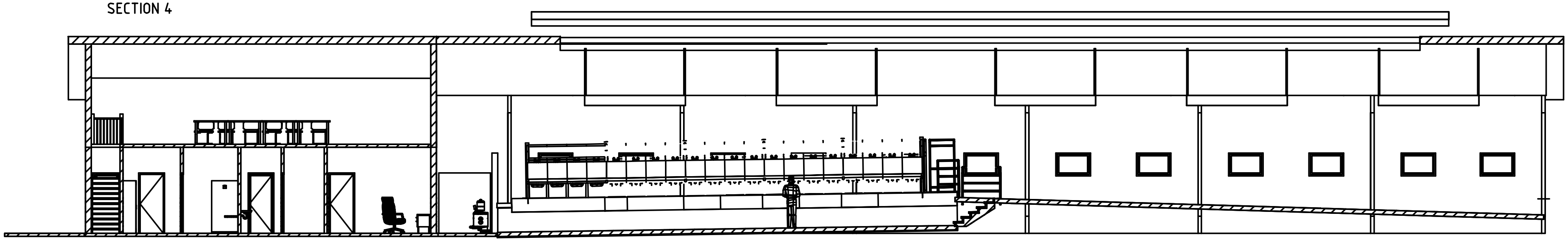
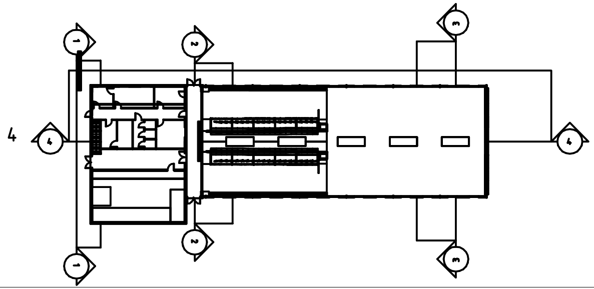


SECTION 1-6



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DeLaval	DATE 2004-12-18
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	SCALE 1:150 A3
DRAWN/DEPT. M CARLSSON	CHECKED/DEPT. CS-PM
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