The Pennsylvania State University

The Graduate School

Intercollege Graduate Program in Agricultural and Biological Engineering

HEAT ABATEMENT TECHNIQUES IN DAIRY HOUSING IN THE NORTHEAST

A Thesis in

Agricultural and Biological Engineering

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

December 2008

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ABSTRACT

The average annual milk production per cow has increased by 424% since the 1940's. While this increase can be accredited to many factors such as breeding, nutrition, modern management and husbandry, one outcome of this increased production is the increase in metabolic heat production. Therefore today's cows are more sensitive to heat stress than in the past, and today's highest producing herds are at highest risk for production losses caused by heat stress.

Heat abatement of these high producing cows is a complex issue. Heat stress cannot be measured simply by the ambient temperature alone. Factors such as solar load, humidity, air exchange, air velocity, and duration of the heat event must also be considered when addressing heat stress.

The "Heat Abatement System Selection Tool" gives producers, consultants, and designers a logical structure to the decision process to develop a heat abatement system best suited for an individual dairy operation based on the geographic location, weather conditions, type of shelter, and management to be used on that operation. The Heat Abatement Selection Tool was developed based on the best research information and field observations available at this time. The tool uses a three step process to arrive at a heat abatement system best suited to the shelter, assuming shade has been provided by the shelter itself. First air exchange of the shelter is optimized, second convective cooling is optimized, and third, if needed, evaporative cooling is added to the system.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to express gratitude to my advisor Dr. Robert Graves for his guidance and encouragement to complete my graduate program. The “old crank” was needed at many points along the path to keep me moving. I want to thank the other members of my committee, Dr. Eileen Wheeler and Dr. Gabriella Varga, for their guidance and encouragement while working on this thesis.

I also need to acknowledge the support given by my wife, Jennifer, and our children. Without their support and encouragement I don’t know if I could have gotten to this point.

Chapter 1:

Introduction

A common problem in dairy housing facilities is providing the necessary heat abatement during the hot summer months. St-Pierre et al. (2003) estimated the US livestock industry could lose approximately $2.4 billion annually in production due to heat stress without the use of some type of heat abatement. The Pennsylvania dairy industry alone represents $74 million of these production loses. With optimum heat abatement it is estimated losses in the PA dairy industry could be reduced 40% to approximately $45 million annually.

Ventilation is a large contributor to the profit potential of a dairy enterprise. Traditionally dairy barns have been built to conserve heat for cold winter months, when the barn must remain above freezing to protect the feeding, milking, and watering equipment kept in the barn. However, the environment desired for summer months is often compromised (Faust and Holmes, 1991).

Heat stress is when the animal's heat gain is higher than its heat loss. The animal produces body heat through metabolism, physical activity, and performance. Heat can also be gained from the environment through radiation from other bodies of higher temperature, convection from the air if at a higher temperature, and conduction from a surface if at a higher temperature. Heat can be lost from the animal through radiation to a body of lower temperature, convection to surrounding air of a lesser temperature, conduction to a resting surface if at a lesser temperature, or through evaporation where heat is lost due to the phase change of water from liquid to vapor (Graves, 2002).

The four modes of energy transfer represented (radiation, convection, evaporation, and conduction) are governed by physical law. For the animal to maintain homeothermy (i.e. no change in core body temperature) energy gains from the transfer modes and from internal metabolic processes must equal energy losses (Hahn, 1985).

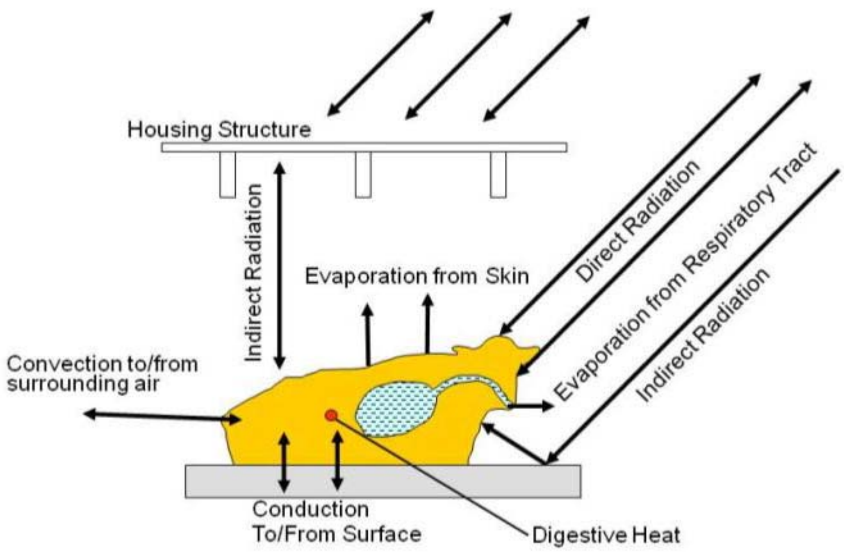

Figure 1.1. Energy exchanges between the animal and its surroundings. Adapted from Hahn (1985) and Graves (2002).

Heat abatement is provided in dairy facilities using four basic procedures. 1) shade is provided for the animals by the shelter to remove the direct radiation heat load; 2) air exchange of the facility is optimized with the use of natural or mechanical ventilation to remove the animal heat and solar gain from the shelter, thus lowering the inside temperature and allowing for increased convective cooling; 3) air velocity within the facility is optimized, at animal level, with mechanical means to further enhance convective cooling of the cow; 4) additional cooling may then be provided by using evaporative cooling to remove heat from the air and/or animals within the facility.

The three most common ways of increasing the air exchange and speed in dairy housing are 1) tunnel ventilation 2) natural ventilation with circulation fans and 3) natural ventilation with high volume low speed (HVLS) fans.

Evaporative cooling can be achieved two ways: 1) the direct cooling of the cow by evaporating water from the skin surface where the heat used to evaporate the water comes mostly from the animal or 2) the cooling of the air where the heat in the air is used to evaporate the water, with the cooler air then circulated around the cow.

Providing adequate quality and quantity of drinking water along with appropriate changes in summer feed management are also important components of heat abatement. During hot weather drinking water demands will increase for cattle (MWPS, 2000). However these specifics are beyond the scope of this discussion.

While much research has been done on all these different heat abatement systems the data and results are scattered throughout the literary base. Design and performance data from these systems has never been combined into a single source documenting the effectiveness of heat abatement systems.

Chapter 2:

Literature Review

2.1: Thermoregulation in dairy cattle

Dairy cows are homeotherms with an effective but complex thermoregulatory system. Mostly of Northern European origin, their system, when in economic production situations, is more commonly overtaxed because of excessive heat than because of cold weather (Wiersma, 1976). Energy expended for maintenance is eventually given off as heat. This heat is dissipated by vaporization, convection, radiation, and conduction (Brody, 1948).

When environmental temperature is considerably below that of body temperature the rate of heat loss in standing animals is mostly by radiation and convection (Brody, 1948). As the environmental temperature rises, evaporative cooling heat loss becomes more important and must increase because of the decreased sensible heat losses of convection, radiation, and conduction (Scott et al., 1983).

Ambient temperature of 24°C to 27°C (75°F to 80°F) is the upper limit at which Holstein cattle may maintain stability of body temperature. Above this temperature husbandry procedures should intervene to prevent or reduce the rise in body temperature (Berman et al., 1985). However, the thermal environment is not simply determined by dry-bulb temperature, it is also influenced by wet-bulb temperature, radiant temperature, and air velocity. Thermal environment close to the animal (i.e. the microenvironment) is also of concern (Sallvik and Walberg, 1984).

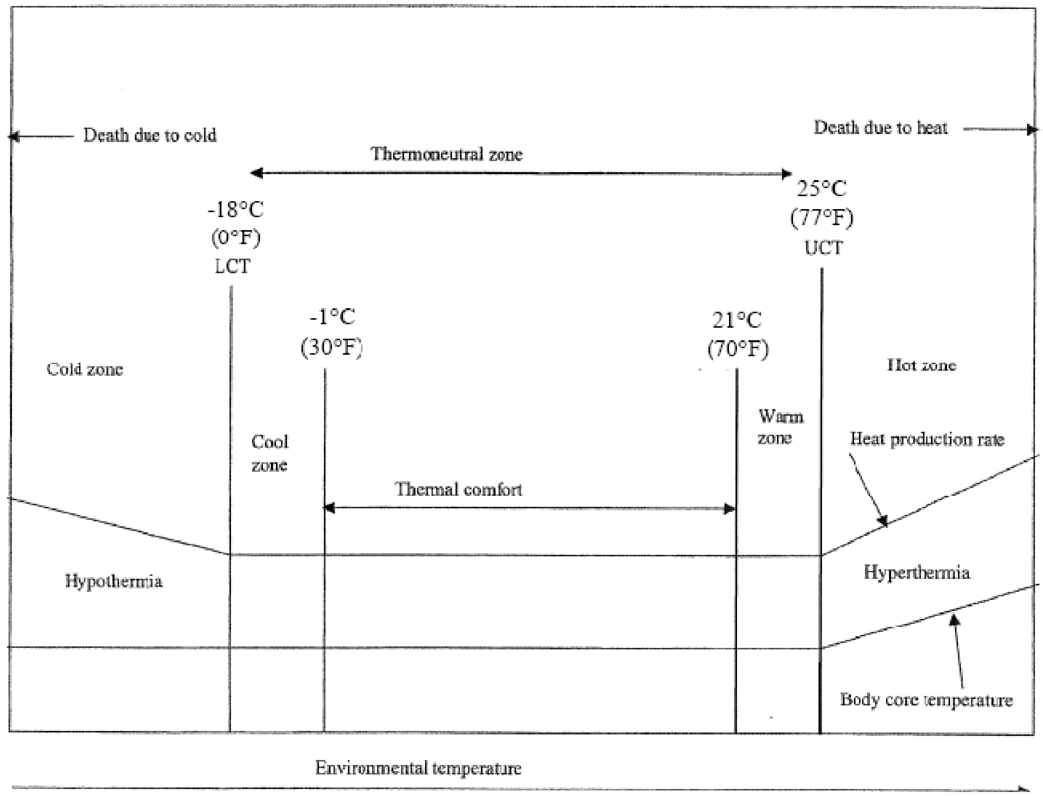

Figure 2.1. Schematic relationship of the animal's body core temperature, heat production and environmental temperature.

Adapted from Kadzere et al. (2002). LCT is lower critical temperature; UCT is upper critical temperature.

2.1.1: Effects of temperature

A drop in milk production begins at about 24°C to 27°C (75°F to 80°F) in Holsteins and 27°C to 29°C (80°F to 85°F) for Jerseys with the decline being steeper for Holsteins than Jerseys. Milk production virtually stops when environmental temperature reaches and is maintained at 38°C (100°F) (Ragsdale et al., 1948). There are three basic milk production temperature zones with relative humidity at 55-70%: a) low temperature zone of decreasing production beginning at -1°C (30°F) for Jerseys and below -12°C (10°F) for Holsteins and Brown Swiss; b) an optimum temperature zone of about -1°C to

24°C (30°F to 75°F) for all breeds; and c) a zone of high temperature production loss above 24°C (75°F) for all breeds (Yeck and Stewart, 1959).

The milk production in high producing animals virtually doubles the metabolic heat production as compared to non-milking animals. Hence a reduction of milk production with increasing temperature reduces heat production and lessens the heat stress on the animal (Ragsdale et al., 1948). When temperature increases, milk production of higher producing cows declines more rapidly than that of lower producing cows (Thatcher et al., 1974). Since convective cooling is dependent on the temperature gradient between body surface and environment, an increase in environmental temperature, with constant air velocity, causes a corresponding decline in the cooling ability leading to heat stress (Thompson et al., 1954).

There are two areas from which moisture can vaporize from animals: external surface and respiratory surfaces. At higher environmental temperatures when non-evaporative cooling is severely reduced, heat dissipation is shifted to cooling by vaporization from outer body and respiratory vaporization. For dairy cattle the vaporization rate between -15°C to 10°C (5°F and 50°F) is nearly the same from outer body and respiratory tract. However, between 10°C and 32°C (50°F and 90°F) there is a fourfold increase in the surface evaporative cooling rate, while the respiratory vaporization rate increases slowly. Vaporization from the respiratory tract is directly affected by the temperature and humidity of the inspired air. Higher temperature and humidity leads to the higher water vapor content of inspired air which decreases vaporization from the respiratory tract. Above 18°C (65°F) the external vaporization heat loss is a significantly larger portion of the total then is the respiratory vaporization, although increased pulmonary ventilation rate also increases cooling by respiratory vaporization. However external vaporization is limited by the "sweating" ability of the cow, and above 21°C to 24°C (70°F to 75°F) the evaporative cooling from both respiratory vaporization and external vaporization is not sufficient to prevent a rise in rectal temperature. The above data was collected in a chamber with air speeds of approximately 0.22 m/s (0.5 mph) (Kibler and Brody, 1950).

2.1.2: Effects of velocity

An increase in the velocity of air, at a temperature lower than the surface temperature of the animal, has the potential to increase the sensible heat loss of the animal. An augmentation in air velocity will shift the upper critical temperature upwards (Scott et al., 1983). An effective ventilation system to reduce heat stress should emphasize the production of high air speed as much as the commonly accepted goal of reducing ambient temperature. Increasing the air velocity lowers the effective temperature producing a wind chill index in hot weather similar to that commonly referred to during cold weather (Timmons, 1989). Between 26°C and 36°C (80°F and 97°F) the rate of rise in rectal temperature was halved with increased air velocity of 1.5 to 3.0 m/s (295 to 590 fpm) as compared to a mean air velocity of 0.5 m/s (98 fpm) (Berman et al., 1985).

Of the four heat dissipation methods (radiation, convection, evaporation, and conduction) only two, evaporative and convective cooling, are affected directly by air speed. Evaporative cooling, because of the high latent heat of vaporization, is by far the more important if the outer surface is moist. However, if the outer surface has little moisture to vaporize, the increased heat dissipation by increasing air velocity is largely due to convective cooling. Convective cooling does not increase linearly but is a function of the square root of the velocity (Thompson et al., 1954).

Winds tend to widen the "comfort zone" at high air temperature where cooling is beneficial. An analysis of the relation between wind and heat loss from cows is complicated by the interaction of several factors. Convective cooling rises with increasing air velocity, but in doing so lowers the temperature of the outer surface causing a decrease in the losses by radiation, conduction, and outer surface vaporization. The convective cooling of the outer surface also reduces evaporation from the respiratory tract by reducing respiration rate and the pulmonary ventilation tract by reducing respiration rate and pulmonary ventilation rate. At temperatures below 35°C (95°F) changes in respiration rate and pulmonary ventilation rate caused by increased air velocity were greater between 0.18 and 2.2 m/s (35 and 440 fpm) than between 2.2 and 4.0 m/s (440 and 790 fpm). Vaporization from the skin increases with rising temperature but tends to decrease with rise in air velocity. The only possible explanation for this decrease in vaporization with rising air velocity is that less moisture from sweating reaches the surface of convectively cooled skin. One possible cause is a slower diffusion rate brought about by diminished blood flow through constricted skin capillaries. This also suggests that as convective cooling increases, the cow limits her sweating (Kibler and Brody, 1954).

However, at 35°C (95°F) there is an increase in the vaporization rate at high velocity, 4.0 m/s (791 fpm), but not at low velocity, 0.18 m/s (35 fpm). The vaporization curve at low velocity has reached its maximum while the corresponding curve for high velocity continues to rise. In brief, evaporative cooling continues to be effective at a higher temperature range with high air velocity if moisture is present. Increasing air velocity shifts the vaporization curve, thereby increasing evaporative heat loss. This increase in evaporative heat loss extends maximum vaporization and the range of physiologically tolerable temperatures to a higher level. The effect of increasing velocity on evaporative cooling and surface temperature was non-linear, similar to the effect of velocity on convective cooling. The effect was greater from 0.18 to 2.2 m/s (35 and 440 fpm) than from 2.2 to 4.0 m/s (440 and 790 fpm) (Thompson et al., 1954).

The effect of air speed on rectal temperatures at 10°C and 18°C (50°F and 65°F) is negligible. However, at 26°C and 35°C (80°F and 95°F) the cows which develop the highest rectal temperatures at low velocity are cooled most by high velocity. These cows were also those with the highest production levels, indicating greater relief for higher producing cows with increased air speed. Air velocity has no effect on heat production in the "thermoneutrality" zone (5°C to 16°C) (40°F to 60°F), but at 35°C (95°F) heat production was higher at higher air velocity indicating greater milk production potential. Overall, higher air velocities enable cattle to maintain normal body temperature during exposure to heat stress that would normally cause a rise in body temperature (Kibler and Brody, 1954).

The higher the milk production and the larger the cow the greater the effect of changing air velocity from 0.22 to 4.0 m/s (43 to 790 fpm) at 35°C (95°F). This may be because heavy milk production is highly correlated with high heat production, and large body size is associated with smaller surface area per unit weight, with consequently greater difficulty in heat dissipation. The results of greater thermal stress may render the larger and heavier milking cows more sensitive to the slightly reduced cooling of reduced air velocity (Brody et al., 1954).

2.1.3: Effects of humidity

The moisture content of the environment affects directly the latent heat loss of the animal and is of major concern at high environmental temperature where sensible heat loss is limited (Scott et al., 1983). Relative humidity has no significant affect on production below 25.4°C (77.8°F). However, above 25.4°C (77.8°F) high humidity accentuates the high temperature effect (Berry et al., 1964).

The absolute decline in Holstein milk production is defined as follows:

$$AD = 3.009 + NL\,(6.404 - 0.08008\,T_{db} - 0.1005\,T_{wb} + 0.001281\,T_{db}\,T_{wb}) \qquad \text{Eq. 2.1}$$

where AD is absolute decline in milk production in pounds per day, NL is normal level of production in pounds per day, and T_{db} and T_{wb} are dry-bulb temperature and wet-bulb temperature in °F, respectively (Berry et al., 1964). Scott et al (1983) later converted this to SI units of:

$$AD = 1.365 + NL\,(1.937 - 0.07036\,T_{db} - 0.10712\,T_{wb} + 0.00415\,T_{db}\,T_{wb}) \qquad \text{Eq. 2.2}$$

where AD is absolute decline in milk production in kilograms per day, NL is normal level of production in kilograms per day, and T_{db} and T_{wb} are dry-bulb temperature and wet-bulb temperature in °C, respectively.

2.1.4: Temperature Humidity Index (THI)

Several indices have been developed and used to predict comfort of environmental conditions. Generally the two environmental parameters considered have been dry-bulb temperature and a measure of moisture content of the air. The most common comfort index is the Temperature-Humidity Index (THI). Originally THI was developed as a comfort index for humans, however it has also been used to evaluate animal comfort. There are three forms of the THI equation (Glickman, 2000).

$$THI = 0.4\ (T_{db} + T_{wb}) + 15 \qquad \text{Eq. 2.3}$$

$$THI = 0.55\ T_{db} + 0.2\ T_{dp} + 17.5 \qquad \text{Eq. 2.4}$$

$$THI = T_{db} - (0.55 - 0.55\ RH)\ (T_{db} - 58) \qquad \text{Eq. 2.5}$$

Where:

T_{db} = dry-bulb temperature in °F

T_{wb} = wet-bulb temperature in °F

T_{dp} = dewpoint temperature in °F

RH = Relative Humidity in decimal percent form

Equations 2.4 and 2.5 are the most used in the literature reviewed. A note should be made that equation 2.5 gives slightly higher THI values, 2 to 4 units, than equation 2.4 when dry-bulb temperature raises over 27°C (80°F) and relative humidity is over 65% or dewpoint temperature is within 9°C (16°F) of the dry-bulb temperature. The difference in values is apparently inherent to the equations and is not explained.

When THI exceeds 72, high producing dairy cows are affected adversely (Armstrong, 1994). Values of THI have been categorized into four hazard levels to develop the “Livestock Weather Hazard Guide” (Whittier, 1993). The ranges are as follows:

Table 2.1. THI hazard levels.

Stress Categories	**THI Value**
Safe	< 75
Alert	75 - 78
Danger	79 - 83
Emergency	≥84

Ravagnolo et al. (2000) compared average test-day yield for milk to THI and observed a decrease of 0.2 kg/cow (0.44 lbs/cow) per unit increase in THI ≥ 72.

THI does not account for the interaction between heat stress and air velocity or heat gain from solar radiation (Buffington et al., 1981). However, Mader et al (2006) suggest a reduction in THI by 2 units for an increase in air velocity of 1 m/s (200 fpm) and an increase in THI of 0.68 for each 100 W/m^2 (32 $Btu/ft^2 \cdot hr$) increase in solar radiation.

2.1.5: Effects of Milk Production

Much of the data collected on the environmental thresholds on heat stress are based on research done in the late 1940's and 1950's (Brody, 1948; Brody et al., 1954; Kibler and Brody, 1950; Kibler and Brody, 1954; Ragsdale et al., 1948; Thompson et al., 1954; Yeck and Stewart, 1959). Annual milk production per cow has increased 424% from 1940 to 2005 from 2,096 kg (4,622 pounds) to 8,879 kg (19,576 pounds) (USDA, 2006).

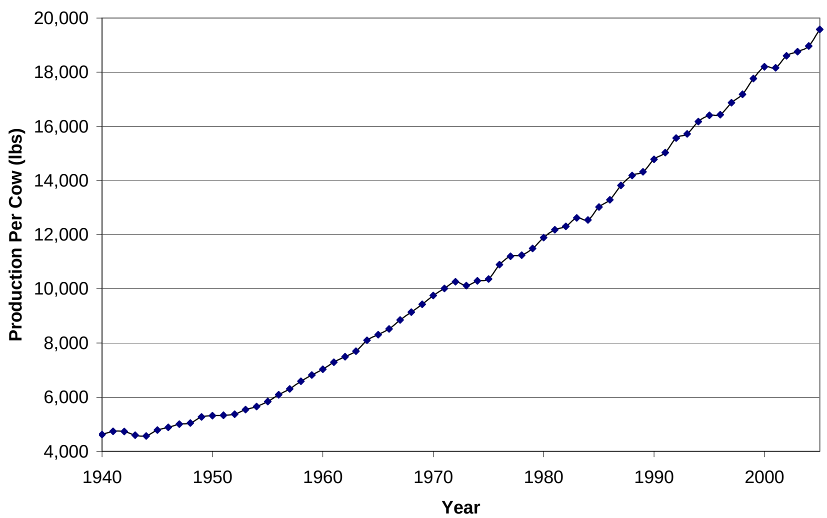

Figure 2.2. U.S. Historic milk production from 1940 to 2005.

Little attention has been paid to the thermoregulatory ability of the modern cow as her capacity to produce milk has increased. The question arises whether the temperature at which cows currently start experiencing heat stress has shifted to a lower point, considering that increased milk production is positively correlated to both feed intake and metabolic heat production. Due to high metabolic heat increment, and especially in the warmer months, high-producing dairy cows may enter heat stress much earlier than currently thought and most certainly before their lower-producing counterparts or the extra heat production has been accommodated by physiological adaptations. Should this be the case, then strategies to reduce heat stress must be developed to enable cows to express their full genetic potential (Kadzere et al., 2002).

Berman (2005) estimated that increasing milk production from 35 to 45 kg per day (77 to 99 pounds per day) decreased threshold temperature by 5°C (9°F). Tillotson and Bickert (1994) found that the widely published standards for livestock heat production do not adequately represent today's high producing cows in modern dairy facilities. The impact of using inadequate heat production standards has led to the under design of ventilation standards as milk production has increased.

2.1.6: Effect of Heat Duration

It is possible that cattle accumulate heat during the hotter parts of the day and then dissipate this heat when conditions are cooler. Cattle will use this mechanism where diurnal variations in climatic conditions are present but will reach a point where the mechanism fails largely because the ambient conditions do not alleviate (Gaughan and Holt, 2004).

Linvill and Pardue (1992) derived the following equation for influence of THI on milk production for a large herd in South Carolina. Production losses were best described as a function of the total hours THI was greater than 74 for the last 4 days (HD74) and the square of the total hours THI was greater than 80 for the last day (HA80S). The following equation was derived:

$$\text{Daily Production (kg)} = 21.48 - 0.51\ \text{HD74} - 0.0099\ \text{HA80S} \qquad \text{Eq. 2.6}$$

where:

HD74 = total hours THI > 74 for the past four days

HA80S = square of total hours THI > 80 for past day

It needs to be noted that equation 2.6 represents the production of a single herd. Therefore the purpose is not to estimate production of other herds, but rather to note the influence of heat stress over time.

Ravagnolo et al (2000) also noted that it is likely that milk yield at test day is affected not only by that days THI, but also by the shape of the heat and humidity curve during a period preceding the test day.

Zulovich et al (2008) suggest that if a cow is allowed to balance her heat over a 24 hour period there is no anticipated milk production loss due to heat stress. However, if the cow cannot balance her heat for 72 hours or more than a production drop would be experienced.

The above information would suggest that the length of the heat event plays a role in animal's response. If an animal is allowed to cool off during the night, typically when the THI is lower, than no production loss should be seen. Dependant on the local climate of where a dairy operation is located this fact can be used to the dairy's advantage.

2.1.7: Effect of Heat Stress on Behavior

Cows stand and seek cooling when their core body temperature reaches 38.9°C (102°F). Core body temperature is a more reliable indicator than either dorsal skin temperature or respiration rates for predicting when cows stand and seek cooling. Standing has the thermal heat loss advantage over lying, because more surface area is available for convection and evaporation to occur (Hillman et al., 2005). Lee and Hillman (2007) also noted cows on pasture stood-up when their core temperature reached 39.0°C (102°F) to allow cooling.

Cook et al (2007) note a shift in activity occurred around a THI of 68. Cows had a reduction on lying time of 3 hrs/day at a THI > 68, which is a typically experienced THI is the upper Midwest during the summer. Therefore the use of more aggressive heat abatement strategies implemented at an activation temperature of around 21°C (70°F) is recommended.

Gooch and Stowell (2003) noted an increase in standing could have an impact on cows in the long run as they may develop increased foot and leg problems.

2.2: Basic Requirements for Heat Abatement

Farm animals try to maintain a constant body temperature so they either lose metabolic heat to their surroundings at the rate it is produced, or their body temperature changes (MWPS, 1990). Bray and Bucklin (1996) recommend the use of heat abatement if 8 of 10 cows have rectal temperatures above 39°C (102.5°F) or if respiration rates are over 80 per minute or if dry matter and milk production drop 10% in hot weather.

Availability of drinking water is critical to the cow's ability to help regulate body temperature. Typical consumption of a milking cow is 130 to 190 liters/day (35 to 50 gallons/day) dependent on production level and the moisture content of the feed ration. However, during hot weather water intake will increase (MWPS, 2000). At higher temperatures non-evaporative cooling is reduced and heat dissipation shifts to cooling by vaporization from the outer body and respiratory vaporization (Kibler and Brody, 1950). Provide 90 cm (3ft) of accessible water trough perimeter for every 10 to 15 cows within a group and at least two watering locations for each group (Graves et al., 2006). For the purposes of the discussion in this publication it will be assumed that adequate drinking water will be provided as a basic element of proper dairy cow husbandry.

In order to provide heat abatement four basic steps need to be taken. 1) Provide shade for the animal to reduce the solar radiation load on the animal. 2) Provide adequate air exchange of the shelter. 3) Increase air velocity at animal level. 4) Increase the cooling capacity of the cow with the use of an evaporative cooling system (either direct or indirect).

Once shade is provided, heat abatement systems can be described in two categories: 1) convective cooling and 2) evaporative cooling. Convective cooling systems use increased air exchange and velocity alone to provide heat abatement while evaporative cooling systems drop ambient air and/or cow temperature by either direct and/or indirect methods. Evaporative cooling systems also usually provide some convective cooling to provide additional heat stress relief.

In the field these systems are often not as easily categorized. In many facilities there are combinations of convective and evaporative cooling being used in the same shelter dependent on the ambient conditions at that time, or the management style of the dairy producer.

2.2.1: Shade

Shade is considered to be essential to reduce loss of milk production and reproduction efficiency, and may be necessary for survival (Armstrong, 1994). A simple shade structure can reduce the radiant heat load on a cow by 30% or more by intercepting the direct solar radiation (Bond et al., 1967). A portion of the radiant load still remains as the shelter roof and/or surrounding environment re-radiate to the animal.

Shades, defined as thermal radiation shields, change the radiation balance of an animal, but do not affect air temperature or humidity. The shade structure should provide at least 4.2 m^2 (45 ft^2) of floor space per cow and preferably up to 5.6 m^2 (60 ft^2). To achieve maximum benefits from a shade structure the cows must have access to feed and water under the shade (Buffington et al., 1983).

Buffington et al (1981) reported an increase of 10.9% and 5.5% more fat corrected milk from cows under shade structure as cows with no shade during two different summer seasons. In an Arizona trial a 6% increase in milk production was observed from providing 3.7 m^2 (40 ft^2) of solid shade per cow vs. no shade at all (Armstrong et al., 2005).

Freestall shelter orientation has an effect on shading. Shelters with a north-south orientation have greater solar radiation exposure than shelters with an east-west orientation. Sunlight can directly enter north-south oriented shelters both in morning and afternoon. Because cows seek shade during hot weather, usage of stalls located on east and west outside walls is greatly impacted when in direct sunlight. Protection from direct sunlight is vital for effective heat stress abatement (Brouk et al., 2001b).

2.2.2: Convective Cooling (Increased Air Exchange and Air Velocity)

Air exchange is the basis for maintaining air quality inside a building (ASAE, 1991). Current recommendations (MWPS, 2000) for hot weather call for at least 13.3 m^3/min (470 cfm) per mature, 635 kg (1400 lbs) Holstein. In some cases, rates twice this amount are being considered the minimum acceptable for new facilities (Stowell et al., 2003). In the Northeast United States the typical goal is 28 to 42 m^3/min (1,000 to 1,500 cfm) per animal during hot weather (Tyson et al., 2004). A ventilation system that provides at least one air exchange per minute is recommended (Bucklin et al., 1991). This ventilation rate can be achieved with either natural ventilation or mechanical ventilation. Bickert and Stowell (1993) documented that elevated rates of air exchange can keep air temperatures within a stocked freestall barn at or below ambient outdoor temperature during the heat of the day. The lowering of temperature is assumed to be from the evaporation of water from surfaces within the shelter.

While increasing rates of air exchange can result in remarkable improvements in heat abatement, it is increasingly evident that airflow at the cow level needs to be increased to achieve the full benefits of increased air exchange (Stowell et al., 2003). Chastain and Turner (1994) proposed that air speed of 1 to 2.2 m/s (200 to 433 fpm) most effectively utilizes fan output and providing airflow at the most efficient range of airspeeds was projected to produce adequate cooling.

Convective cooling systems include: tunnel ventilation, a specific type of mechanical ventilation, and axial circulation fans or high volume low speed (HVLS) fans used in conjunction with natural ventilation.

2.2.2.1: Tunnel ventilation

Tunnel ventilation increases convective and evaporative cooling by providing both increased air exchange and increased air velocity within the shelter. The entire air inlet is located at one end of the building in the end wall or the extreme end of the sidewalls. All the air enters through these openings and flows the length of the building to the exhaust fans at the opposite end. This arrangement produces a very desirable "wind tunnel effect" throughout the entire building that provides more uniform velocity and distribution, eliminates blasts of high velocity air, and minimizes dead air pockets (Bohanon and Rahilly, 1988). The principal advantage of tunnel ventilation is the provision of high air velocities throughout the shelter, regardless of prevailing wind conditions (Bottcher et al., 1995a).

Tunnel ventilation however is a hot weather ventilation strategy for cows, since a relatively frequent air exchange and rapid air speed over the cows is provided. The air exchange needed during cold and mild weather is much less. Therefore, an additional ventilation system, using strategically placed inlets and fans, or natural ventilation should be used for cold and mild weather conditions (Tyson et al., 2004).

Tunnel ventilation design is based on cross sectional area and air velocity. The minimum air velocity should be 1.55 m/s (300 fpm), to provide cooling, with the inlet sized at 0.25 m^2 (2.5 ft^2) per 28 m^3/min (1000 cfm) of fan capacity, to provide proper inlet velocity. The required fan capacity is found by multiplying the cross sectional area of the housing area by the desired air speed. A continuous inlet across the entire width of the building is preferred to provide a more uniform velocity distribution (Tyson et al., 2004).

Beyond the animal health and productivity benefits, producers benefit from working in a much more pleasant and comfortable environment. Observations also show a dramatic reduction in noise level over conventional sidewall ventilation with additional mixing fans (Faust and Holmes, 1991).

Lacy and Czarick (1992) found that while total power usage was 50% higher for tunnel ventilation than conventional natural ventilation with additional cooling fans over the entire grow out period for broilers. On individual hot days, +35°C (95°F) power usage was only 20 to 30% higher in tunnel ventilation. The difference in total power usage over the entire grow out period and daily power usage is due to the tunnel houses being unable to be naturally ventilated during cooler periods. However, total production costs were 0.33 cents/kilogram (0.15 cents/pound) lower in the tunnel ventilated houses due to higher weight and slightly better feed conversion. The lower production cost led to an overall net income of $135 per flock after subtracting the additional electricity.

Xin et al. (1994) also showed that the kilo-Watt-hour usage per 1,000 birds marketed was more for conventional natural ventilated houses with additional cooling fans (389 kW·h per 1,000 birds) than tunnel ventilated houses (302 kW·h per 1,000 birds) under summer ventilation conditions. This was due to the use of fewer larger fans with greater efficiency in the tunnel ventilation systems.

Lacy and Czarick (1992) also found that tunnel ventilation lowered the inside temperature 2.8°C to 4.4°C (5°F to 8°F) more than conventional natural ventilation. This increase was believed to come from higher air exchange and velocity resulting in greater evaporative cooling.

The ideal tunnel ventilation design is to place all fans in one end wall and all inlets in the opposite end wall. Practical considerations may dictate that some exhaust fans be placed on a sidewall. For all practical purposes, there will be minimal differences created by alternate installation placements of the fans or inlets as long as they are as near as possible to the end wall. There may be some subtle differences in the immediate vicinity of the fans or inlets, but the amount of air being exhausted, and therefore the air velocities, along most of the shelter length will not be affected (Timmons, 1989).

Simmons et al. (1998) determined that if fans must be placed both in the endwall and sidewall the adjacent fan inlets should be separated by 30 cm (1 ft), i.e. sidewall fans should be placed a minimum of 30 cm (1 ft) from the endwall.

Ford and Riskowski (2003) indicated windbreak walls installed downwind of tunnel ventilated shelters in an effort to lessen odor concerns of downwind neighbors had negligible adverse effect on fan performance when installed at least 4 times the fan diameter downstream.

Xin et al. (1994) found that vertical temperature gradient, lengthwise temperature variations, and crosswise temperature variations were negligible in tunnel ventilated broiler houses during summer ventilation, because of the large ventilation rate. Wheeler et al. (2003) found that on average the temperature difference from inside to outside was +2.6°C (+4.7°F) for the tunnel ventilated broiler house studied. The maximum difference between the maximum and minimum monitored interior temperature was less than 2.8°C (5°F), which indicated acceptable temperature uniformity. Czarick and Tyson (1989) cite that in many instances production problems associated with tunnel ventilated houses are the direct result of poor ventilation design and operation. Unlike conventional curtain-sided houses where air exchange and distribution are mostly uncontrollable, the operator of a tunnel ventilated house has a high level of control over the environment. If the ventilation system is not properly designed or installed, the producer's ability to control the environment will be limited and production will suffer.

Gooch and Stowell (2003) reported a slight overall advantage in mean inside air temperature and temperature-humidity index (THI) of tunnel ventilated freestalls over naturally ventilated barns with circulation fans. However airspeeds were not uniform along the lengths and widths of barns. Measured airspeeds within the lower portion of many tunnel-ventilated barns were noticeably lower than the design airspeed. Measured airspeeds in the central areas, like drive-through alleys, and higher off the floors were usually greater than in the corresponding freestall areas and other occupied cow spaces. This shows that airflow naturally channels towards those areas with least resistance to air movement and away from areas offering more resistance due to blockage (cows and/or freestalls). Longer barns appear to have a more pronounced airflow channeling effect resulting in little air movement at cow level. They also noted a change in animal behavior. In two of the three tunnel-ventilated barns, the tendency observed was that more cows were on their feet (standing at a bunk, in cow alleys, or in stalls) within upwind quadrants, to expose their bodies to higher levels of airflow.

2.2.2.2: Circulation Fans with Natural Ventilation

In this system the shelter's natural ventilation is first maximized to increase air exchange. High open sidewalls increase the natural ventilation rate. The current thinking is that the 4.3 to 4.9 m (14 to 16 ft) eave height is the best choice in barns (Bray et al., 1994) when looking at effect of barn eave height on interior temperature. In an evaluation of several naturally ventilated freestall barns, Stowell and Bickert (1994) found that those exposing large amounts of open wall area to cows (on a per-cow basis) provided a more suitable environment with less interior variation. An open ridge vent should also be provided (Graves et al., 2006).

Circulation fans can be placed in natural ventilated freestalls shelters to increase the air velocity felt by the animals. Total heat loss, measured with a portable calorimeter, increased by approximately 380 W/m^2 (120 $Btu/hr \cdot ft^2$) when air speed over the cow was increased from 0.1 m/s to 2.2 m/s (20 fpm to 433 fpm) (Hillman et al., 2001). Supplemental air flow decreased respiration by approximately 7 breaths per minute and body temperature by approximately 0.24°C (0.43°F) (Brouk et al., 2003a). Chastain and Turner (1994) found that cooling was not greatly enhanced for velocities greater than 2.2 m/s (433 fpm) and recommended air velocities of 1 to 2.2 m/s (200 to 433 fpm) for cooling system design. Bottcher et al (1995a; 1995b) demonstrated that a conventional axial circulation fan can maintain an air speed of 2.2 m/s (433 fpm) for a distance approximately 10 times its diameter and a width approximately 3 times its diameter along the center line of the fan. Also noted was that direct drive fans tend to generate narrower jets of air with a longer throw than belt drive fans due to differences in blade design and speed.

Fuquay et al (1993) compared productive responses of lactating dairy cows under fans in freestalls shelters with similar cows in freestall shelters with no fans. Fans provided approximately 1.3 m/s (262 fpm) of air velocity in the freestall area. Cows under fans consistently had lower rectal temperatures and approached their thermoneutral normal for several hours each night while controls had elevated rectal temperatures for the entire diurnal cycle. While neither average daily milk production nor milk fat differed between the control and fan groups during the 9 week study, persistency of milk production was higher, 90.6% vs 80.0% for cows exposed to fans. Also it was noted that control cows were able to maintain their milk production for several weeks at the expense of body tissues before differences in persistency were observed. The cows with no fans lost 6.3 kg (13.9 lbs) of body weight as compared to those with fans who gained 20.2 kg (44.5 lbs) of body weight. This suggests that over a longer time period an overall difference in milk production would be seen.

2.2.2.3: HVLS (High Volume Low Speed) Fans with Natural Ventilation

Paddle type ceiling fans have been used in the poultry industry to provide air mixing and increase air velocity to promote convective heat loss. Typical fan diameters range from 1.32 m to 1.52 m (52 in to 60 in). However these paddle fans concentrate air flow movement near the floor level with minimum velocity effects at more than 0.3 m (12 in) above the floor. While capable of creating an air velocity of 2 m/s (400 fpm) directly under the fan, the velocity quickly drops to the minimum required 1 m/s (200 fpm) at 3 m (10 ft) from the center of the fan (Timmons and Baughman, 1985).

Bottcher et al. (1998) found similar results when using a much larger 2.5 m (8.2 ft) diameter paddle fan. While able to create air velocities at or above 2 m/s (400 fpm) under the fan, and to a distance of 2.5 m (8.2 ft) from the center of the fan, the velocity dropped to 1.75 m/s (350 fpm) by 3.75 m (12.3 ft) from the center of the fan, and just above 1 m/s (200 fpm) by 5 m (16.4 ft) from the center of the fan. The area under the fan that had velocities at or above 2 m/s (400 fpm) can be defined as two times the fan's diameter.

Kammel et al (2003) conducted a field study of three different freestall barns (three row, four row, and six row) using paddle fans with diameters of 6.1 m to 7.3 m (20 to 24 ft). These fans are commonly referred to as High Volume Low Speed (HVLS) fans. Velocity data was collected from these barns at a point 1.5 m (5 ft) from the floor. In the three row barn, 14.6 m (48 ft) wide by 58.5 m (192 ft) long, three fans were mounted at a 4.3 m (14 ft) height and spaced 20.7 m (68 ft) on center down the center line of the head-to-head stalls. Horizontal velocities of 1 to 1.5 m/s (200 to 300 fpm) were found along most of the feed bunk. Horizontal velocities were highest, up to 2.5 m/s (500 fpm) at several locations near the fan in the west outside freestall platforms, which in fact was the leeward side of the shelter during data collection. Horizontal velocities were 1 to 1.5 m/s (200 to 300 fpm) at most places along the head-to-head freestall platforms and the outside row of freestall platforms.

In the four row barn, 29.5 m (97 ft) wide by 134 m (440 ft) long, seven fans were mounted at a 4.9 m (16 ft) height and spaced 18 m (60 ft) on center along the center of the feed driveway. Horizontal velocities were highest, up to 2 m/s (400 fpm) at the feed bunk lines. Horizontal velocities measured at the center of the head-to-head freestall platforms were usually lower than 1 m/s (200 fpm). Horizontal velocities were often less than 0.5 m/s (100 fpm) along the outside alleys.

In the six row barn, 33 m (109 ft) wide by 106 m (349 ft) long, five fans were mounted at a 4.9 m (16 ft) height and spaced at 18 m (60 ft) on center on the center line of the feed driveway. Horizontal velocities were highest, up 1.5 m/s (300 fpm) at the feed bunk lines. Horizontal velocities measured at the rear of the head-to-head freestall platforms were 0.5 to 1.5 m/s (100 to 300 fpm). Horizontal velocities were sometimes less than 0.5 m/s (100 fpm) along the leeward stall row especially near the holding area on the north side of the barn.

In both the 3 row and 6 row barn configuration the outside wind direction seemed to influence the air speed of the outside walls more than the HVLS fans, with the highest air speeds at the windward sidewall and/or endwall.

While the three row barn configuration seems to meet the minimum of air speed for enhanced convective cooling, 1 m/s (200 fpm), the four and six row barns fall short of the minimum airspeed needed in the freestall area. This may be in part due to the smaller floor area covered by each fan in this barn. From the data presented an observation can be made that the area covered by the HVLS fan with a velocity of 1.0 to 1.5 m/s (200 to 299 fpm), at the 1.5 m (5 ft) level, is approximately two times the HVLS fan diameter.

Worley and Bernard (2005; 2006) concluded that air speeds were more uniform throughout a 30.5 m (100 ft) wide 4 row freestall barn, but were significantly lower in critical areas with HVLS fans as compared to conventional axial fans. While HVLS fans provided a more even airflow throughout the barn than conventional 0.9 m (36 in) axial fans located at approximately 6 m (20 ft) intervals along the feed bunk and over the freestalls, the air speeds produced by the HVLS fans were considered lower than desired in the most critical areas of the feed line and freestall area. The average internal temperature of cows cooled with HVLS fans were approximately 0.2°C (0.3°F) higher than those cooled by conventional axial circulation fans, with the maximum difference of 0.5°C (0.9°F) in the early evening. Based on this, the HVLS fans do not appear to cool cows as effectively in the climatic conditions common to the southeastern US.

2.2.3: Evaporative Cooling

Summer conditions in the southeastern United States and other areas with similar climates require cooling below ambient temperature for optimum milk production and breeding efficiency. Therefore, supplemental cooling methods must be used to increase the cow's ability to lose heat (Bucklin et al., 1991). Brouk et al. (2003a) reported supplemental airflow alone was only a small improvement over no cooling at all when looking at heat stress parameters of respiration rate and body temperature.

Evaporative cooling can be broken down into two main categories, direct and indirect. With indirect evaporative cooling a system is used to lower the ambient air temperature by evaporating water into the air, and then circulate that cooler air around the cow to increase convective cooling. This can be done with evaporative pads where ambient outside air is drawn though the pad while water is circulated over the pad. Heat contained in the entering air is used to evaporate the water. Thus the dry bulb temperature is lowered, but the relative humidity is increased (Wheeler, 1996). This same principle can be followed with high pressure misters or foggers where the water is injected directly into the air stream. The water particles are of small enough diameter that they are evaporated before falling to the surface. Once again the heat contained in the air is used to evaporate the water, lowering the dry bulb temperature and raising the relative humidity. The latter systems are often termed fogging systems using relatively high water pressures, e.g. over 700 kPa (100 psi), to provide a fine mist (Bottcher et al., 1993).

Direct evaporative cooling uses low pressure sprinkler nozzles to wet the skin of the cow. The droplet must be large enough to penetrate the hair coat and wet the skin. Once the skin is wetted it is then allowed to dry. This drying or evaporation of the water thus removes heat directly from the cow to vaporize the water. This process will also increase the relative humidity of the air in the building, so proper air exchange must be provided within the facility.

The major difference between direct and indirect evaporative cooling is whether the cow's skin is wetted or not. Care must be taken to not cover the animal with a fine layer of water on top of the hair coat, trapping a layer of air between the skin and the water film. This will act as an insulator and may increase the severity of heat stress by reducing convective cooling (Armstrong, 1994). Also as the fine droplets cling to the animal's outer hair coat the heat for evaporation comes from the air rather than from the body (Hahn, 1985).

2.2.3.1: Indirect Evaporative Cooling (Cooling Pads and High Pressure Foggers)

Even in more humid areas, the daytime relative humidity is usually sufficiently low for beneficial evaporative cooling. The number of hours with THI ≥ 79 was reduced by between 64.3% to 100% for 17 sites in Oklahoma with the use of a 70% efficient evaporative cooler (Huhnke et al., 2004). Cattle housed in tiestall barns with evaporative cooling had lower respiration rates (65.7 vs. 70.3 breaths/minute) and body temperatures during the afternoon period than tunnel ventilation alone. Evaporative cooled barns also had a greater percentage of July and August hours at a THI level below 70 and the hours in the 85 to 90 THI category were eliminated during the hours of 1:00 pm to 8:00 pm (Brouk et al., 2003b).

Overall maximum afternoon temperature was 2.9°C (5.2°F) cooler, THI was 4.9 points lower and relative humidity 23.6 percentage points higher in a four row, tunnel ventilated freestall barn with evaporative pads as compared to ambient conditions. Similar differences in temperature and THI were also observed in a six row, tunnel ventilated freestall barn with evaporative pads (Smith et al., 2005b).

Smith et al. (2006a) evaluated the effectiveness of evaporative cooling using adjacent freestall shelters in northern Mississippi. Tunnel ventilation with evaporative cooling pads increased the humidity by 22 percentage points; however cows received 84% less exposure to THI > 80 compared to the adjacent shelters with either circulation fans and sprinklers or just circulation fans. Tunnel ventilation with evaporative cooling pads lowered the peak inside temperature by 5.2°C (9.4°F), reduced respiration rate by 13.1 breaths/min, lowered the rectal temperature by 0.4°C (0.7°F), and raised milk yield by 2.6 kg/cow/day as compared to the adjacent shelter with circulation fans and sprinklers. In a later study (Smith et al., 2006b) tunnel ventilation with evaporative cooling pads lowered the peak inside temperature by 3.1°C (5.6°F), reduced respiration rate by 15.5 breaths/min, lowered the rectal temperature by 0.6°C (1.1°F), and raised milk yield by 2.8 kg/cow/day as compared to the adjacent shelter with just circulation fans.

Harner et al (2007) recommend using 0.22 L/min/m^2 (0.33 gal/hr/ft^2) for average consumptive use when designing evaporative cooling pad systems.

Bray et al (1994) compared indirect evaporative cooling with a high-pressure fogger system to a direct evaporative cooling system of low volume sprinklers in order to lower water usage. Both systems effectively cooled cows and consumed comparable quantities of water. However, the high pressure fog system did have an advantage of cooling the cows without depositing significant quantities of water on the alley floor or in the freestalls.

2.2.3.2: Direct Evaporative Cooling (Low Pressure Sprinklers)

Hillman et al (2001) showed, with the use of a portable calorimeter, that Q_e, heat loss by evaporation, reaches a maximum of about 239 W/m^2 (76 Btu/hr·ft^2) when natural sweating reaches its maximum at about 350 gm/m^2·hr (1.15 oz/ft^2·hr). Q_e can be increased through the use of direct evaporative cooling. This process is accomplished by directly wetting the skin surface and fur layer followed by convective cooling. The surface moisture takes up much of the heat conducted through the skin as the moisture evaporates from the wet skin and fur layer, which in the process, cools the skin and allows it to receive more body heat from the internal core. In other words, sensible heat is converted to latent heat. Since the latent heat transfer to the ambient is driven by vapor gradient between the skin surface and the ambient, the level of moisture in the air becomes important, and air velocity speeds up the heat and moisture removal processes (Gebremedhin and Wu, 2002).

Seath and Miller (1948) showed that when cows were removed from sunshine, sprinkled with water and then subjected to a gentle breeze produced by a fan, they showed rapid changes toward normal body temperature and respiration rate. Shade alone showed a small change in that direction, while fan alone and sprinkling alone was intermediate in their effects.

Q_e, heat loss by evaporation, was increased from a maximum of 239 W/m^2 (76 Btu/hr·ft^2) with no wetting and a 2.2 m/s (433 fpm) airspeed to 568 W/m^2 (180 Btu/hr·ft^2) with a 40 minute wetting interval and 871 W/m^2 (276 Btu/hr·ft^2) with a 20 minute wetting interval with the same 2.2 m/s (433 fpm) airspeed. At the same time Q_r, radiant heat loss, and Q_c, convective heat loss, were lowered due to the evaporative cooling, however the total heat loss from the animal was increased by approximately 220 W/m^2 (70 Btu/hr·ft^2) and 400 W/m^2 (127 Btu/hr·ft^2) with 40 minute and 20 minute wetting intervals respectively. Water was applied until the hair coat was saturated or until excess water would drip off the side of the cow. Wetting immediately cooled the dorsal surface by 4°C (7.2°F) and lowered respiration rate by 18 breaths per minute. Rectal temperatures were also lowered by 0.5°C/hr (0.9°F/hr) of cows that were wetted every 20 minutes with a 2.2 m/s (433 fpm) airflow as compared to a 0.2°C/hr (0.36°F/hr) rectal temperature rise with no wetting or fans (Hillman et al., 2001).

In a later study Hillman et al (2005) observed the core body temperature of lying cows rose at a rate of 0.6°C/hr (1.1°F/hr) when exposed to fan cooling alone. When standing under fans without sprinklers core body temperature remained unchanged. However when standing under feed line sprinklers and fan cooling core body temperature fell at 0.7°C/hr (1.3°F/hr). Fan cooling alone was therefore deemed inadequate.

Chastain and Turner (1994) indicated a saturated hair coat holds 563 g/m^2 (1.85 oz/ft^2) of water. Using a mean trunk diameter of 0.7 m (2.3 ft) and back length of 1.4 m

(4.6 ft) it was estimated that 0.9 L (0.24 gal) of water is required to saturate the hair coat on the dorsal surface of a 600 kg (1300 lbs) Holstein. The spray period to saturate the hair coat ranged from 0.5 to 2 minutes depending on nozzle size. Furthermore they noted that field experience indicated that cows are attracted to the spray after they became acclimated to the system. Therefore, nozzles with low flow rates and longer spray periods are recommended for cooling systems used in the feeding area, while larger flow rates and shorter spray periods could be used in the holding area or exit lane since cows are more confined.

Strickland et al (1989) showed an increase in daily milk production of 2.1 kg/cow (4.6 lbs/cow) from 18.1 kg/cow (39.8 lbs/cow) to 20.2 kg/cow (44.4 lbs/cow) with the use of a direct evaporative cooling system as compared to no cooling. Turner et al (1992) showed a daily milk production increase of 3.6 kg/cow (7.9 lbs/cow), or 15.8%, for cows cooled with a direct evaporative cooling system mounted at a feed bunk as compared to no cooling. Lin et al. (1998) showed that daily milk production was about 3.0 to 3.4 kg/day (6.6 to 7.5 lbs/day) greater for cows being cooled with sprinklers over those with just fans or allowed time outside. Barn cooling systems that wet the animal leading to evaporation of water directly from the skin, are more effective than the other evaporative cooling systems that merely lower the air temperature (Frazzi et al., 2002).

There was a significant difference in total 60 day production of 1.4 kg per day post-partum for preparturient cows housed in a shelter with sprinklers, fans, and shades over the feed bunk versus a shelter with only sprinklers over the feed bunk (Urdaz et al., 2006).

Brouk et al (2003a) looked at the effect of sprinkling frequency on the performance of a direct evaporative system. They showed a decrease in the respiration rate of 12 breaths/min when moving from a 15 minute to a 10 minute frequency. An additional decrease of 12 breaths/min was seen when going to a 5 minute frequency. Similarly body temperature decreased by 0.25°C (0.45°F) and 0.35°C (0.63°F) when moving from 15 minutes to 10 minutes and 10 minutes to 5 minutes, respectively. They concluded that under severe heat stress soaking every 5 minutes with fan cooling will be the most effective, and under periods of moderate stress soaking every 10 minutes may be adequate. Reducing soaking frequency when temperatures are lower could also significantly reduce water usage.

While direct evaporative cooling systems do an excellent job of cooling cows these systems can also use large volumes of water (Bray et al., 1994). Strickland et al. (1989) showed a water usage of 454 L/cow·day (120 gal/cow·day) for cooling, while Turner et al. (1992) showed a water usage of 312 L/cow·day (83 gal/cow·day) for cooling. Because high water demand and waste water runoff continues to be a problem for dairies, a decrease in the use of water for cooling systems is desirable (Lin et al., 1998).

Means et al (1992) compared three water application rates of 216 L/cow·day (57 gal/cow·day), 321 L/cow·day (85 gal/cow·day), and 456 L/cow·day (120 gal/cow·day) for a direct evaporative cooling system. Cow productivity and cow comfort did not change with respect to water application rates. Using an application rate of 216 L/cow·day (57 gal/cow·day), Montoya et al (1995) showed that a total of 4.0 L (1.1 gal) per cow per hour evaporated in the barn, and an estimated 2.7 L (0.7 gal) of water per cow per hour evaporated from the cows' hair coat. An estimated 23% of the water emitted by nozzles evaporated and an estimated 15% of the total water applied was evaporated from the cows' hair coats. Evaporating 4.0 L (1.1 gal) of water during 1 hour absorbs energy at a rate of 2708 W (9242 Btu/hr) and evaporating 2.7 L (0.7 gal) of water per hour requires 1828 W (6237 Btu/hr). Both of these values are much greater than the tabulated value (ASAE, 1991) of the sensible heat output of 300 W (1024 Btu/hr) for a 500 kg (1100 lb) dairy cow during a 1 hour period. This indicates that the potential exists to further reduce the quantity of water applied by the cooling system and still maintain a comfortable environment for dairy cows.

In an effort to conserve water when cooling cows, some producers are soaking cows as they leave the parlor on their way back to the freestall barn equipped with circulation fans. Because the opportunity time for wetting is only about two seconds while the cow walks a distance equal to her body length, the nozzles must emit a high flow rate of water. Fan spray nozzles with a flow rate of at least 30 L per minute (8 gpm) at 275 kPa (40 psi) are effective (Wiersma and Armstrong, 1983).

Kendall et al. (2007) showed that cows cooled with shade and sprinklers prior to afternoon milking had reduced body temp of 0.6 °C (1.1 °F) vs. cows with no cooling. Cooling was also noted to continue for approximately one hour after treatment at which point body temperature began to rise, but remained below the body temperature of non-cooled cows for the remainder of the day until such time as the non-cooled cows' body temperature cooled during the night time due to diurnal temperature patterns. Araki et al. (1985) showed cows cooled by fans and sprinklers during morning and afternoon milking maintained lower body temperatures throughout the day then the non-cooled control group.

2.2.3.3: Combinations of Evaporative Cooling

Bucklin and Bray (2005) compared cows housed in a barn using indirect evaporative cooling during the day and direct evaporative cooling at night to a barn that used direct evaporative cooling 24 hours per day. Cows housed in the barn using a combination of systems consistently showed a higher body temperature, however body temperatures in both barns varied greatly.

Brouk et al. (2005) indicated that heat stress was reduced more by the combination of cooling the air and feed line soaking during both the afternoon and night than night only.

Recent research would indicate that a combination of using evaporative cooling to cool the air and a low pressure soaker system to soak the cow can along with adequate air exchange and velocity be used to effectively manage heat stress in hot humid climates. Matching the cooling strategy with the climate is essential to manage the impact of heat stress in dairy cattle (Smith et al., 2005a).

2.2.4: Summary of Heat Abatement Techniques

The effects of various heat abatement techniques found throughout the literature has been summarized in the table below.

Table 2.2. Summary of heat abatement techniques.

	Increased Total Heat Loss	Respiration Rate	Body Temperature	Peak Inside Temperature	THI
Increased Velocity	+ 380 W/m^2 (+120 $Btu/hr{\cdot}ft^2$) air speed increased from 0.1 m/s to 2.2 m/s (20 fpm to 433 fpm) (Hillman et al., 2001)	-7 breaths/min vs. no cooling after 90 minutes (Brouk et al., 2003a)	-0.24°C (-0.43°F) vs. no cooling after 90 minutes (Brouk et al., 2003a)		
			No change when standing under fans without sprinklers (Hillman et al., 2005)		
		-14 breaths.min w/ air speed of 1.5 to 3.0 m/s vs. 0.5m/s (295 to 590 fpm vs. 100 fpm) (Berman et al., 1985)	Rate of increase was halved by air speed of 1.5 to 3.0 m/s vs. 0.5 m/s (295 to 590 fpm vs. 100 fpm) (Berman et al., 1985) (Fuquay et al., 1993)		
Tunnel Ventilation Alone				-0.4°C (0.7°F) vs. natural ventilation w/ axial circulation fans. However natural ventilated shelters appeared to cool slightly faster as outside temperature drops at night. (Stowell et al., 2001)	-0.3 vs. natural ventilation w/ axial circulation fans. (Stowell et al., 2001)

Table 2.2. (continued)

	Increased Total Heat Loss	Respiration Rate	Body Temperature	Peak Inside Temperature	THI
Tunnel Ventilation with Evaporative Cooling		-4.6 breaths/min vs. tunnel alone (Brouk et al., 2003b)		-2.9°C (-5.2°F) vs. outside ambient (Smith et al., 2005b)	-4.9 vs. outside ambient (Smith et al., 2005b)
		-13.1 breaths/min vs. circulation fans and sprinklers (Smith et al., 2006a)	-0.4°C (-0.7°F) vs. circulation fans and sprinklers (Smith et al., 2006a)	-5.2°C (-9.4°F) vs. circulation fans and sprinklers (Smith et al., 2006a)	
		-15.5 breaths/min vs. circulation fans only (Smith et al., 2006a)	-0.6°C (-1.1°F) vs. circulation fans and sprinklers (Smith et al., 2006a)	-3.1°C (-5.6°F) vs. circulation fans and sprinklers (Smith et al., 2006a)	
Direct Evaporative Cooling	+220 W/m^2 (+70 Btu/hr·ft^2) 40 minute wetting interval w/ 2.2 m/s (433 fpm) air speed vs. no wetting w/ same air speed	-18 breaths/min vs. no cooling (Hillman et al., 2001)	-0.5°C/hr (-0.9°F/hr) 20 minute wetting interval w/ 2.2 m/s (433 fpm) air speed vs. no cooling (Hillman et al., 2001)		
	+400 W/m^2 (+127 Btu/hr·ft^2) 20 minute wetting interval w/ 2.2 m/s (433 fpm) air speed vs. no wetting w/ same air speed (Hillman et al., 2001)		-0.7°C/hr (-1.3°F/hr) standing under fans w/ feed line sprinklers vs. under fans alone (Hillman et al., 2001)		

Table 2.2. (continued)

	Increased Total Heat Loss	Respiration Rate	Body Temperature	Peak Inside Temperature	THI
Direct Evaporative Cooling (continued)		-16 breaths/min	-0.43°C (-0.77°F)		
		15 minute wetting interval w/o fan vs. no cooling after 90 minutes			
		-27 breaths/min	-0.77°C (-1.39°F)		
		15 minute wetting interval w/ fan vs. no cooling after 90 minutes			
		-19 breaths/min	-0.47°C (-0.85°F)		
		10 minute wetting interval w/o fan vs. no cooling after 90 minutes			
		-39 breaths/min	-1.04°C (-1.87°F)		
		10 minute wetting interval w/ fan vs. no cooling after 90 minutes			
		-34 breaths/min	-0.76°C (-1.37°F)		
		5 minute wetting interval w/o fan vs. no cooling after 90 minutes			
		-49 breaths/min	-1.40°C (-2.52°F)		
		5 minute wetting interval w/ fan vs. no cooling after 90 minutes (Brouk et al., 2003a)			

2.3: Natural Ventilation

Natural ventilation is driven primarily by two forces: thermal buoyancy and wind speed. During the summer season, natural ventilation is driven mostly by wind forces to provide air exchange and distribution. Thermal Buoyancy is decreased due to the limited temperature difference between the indoor and outdoor air.

Ventilation due to wind forces can be expressed by the following empirical equation (Hellickson et al., 1983):

$$Q = E\ A\ V_w \qquad \text{Eq. 2.7}$$

Where:

Q = ventilation rate (m^3/s)

E = effectiveness of opening due to building orientation

0.50 to 0.60 for perpendicular winds

0.25 to 0.35 for diagonal winds

A = area of inlet opening (m^2)

V_w = effective wind velocity adjusted for inlet height and building exposure (m/s) [See Equation 2.8]

Note V_w is the effective velocity adjusted for inlet height and building exposure. This is done to address two concerns. First, commonly published design wind speeds are taken at a standard height of 10 m (33 ft) above the ground. The planetary boundary layer causes wind speed at this standard height to be higher than at inlet height. Secondly, an exposure variable is used to adjust the wind speed due to upwind disturbances in the terrain.

$$V_w = V_o (h_x/h_o)^a \qquad \text{Eq. 2.8}$$

Where:

V_w = effective wind velocity (m/s)

V_o =wind velocity at standard height (m/s)

h_x = height to center of inlet opening (m)

h_o = standard height (m)

a = exposure variable dependant on upwind terrain

0.14 for very smooth terrain such as a lake surface

0.20 for smooth terrain such as smooth open agricultural fields

0.28 for scattered trees and small buildings upwind

0.40 for rough terrain with tall trees and/or buildings

Exposure of the barn to local winds is critical to successful natural ventilation. Naturally ventilated barns are best located on high ground with open space around them. An upwind obstruction can disturb airflow at a distance of 5 to 10 times its height, and reduce overall wind velocity available for ventilation as seen in the exposure variable, a, of equation 2.8. When allowed to choose, cows avoid these areas downwind of objects during hot weather (Stowell and Bickert, 1994). A minimum of at least 15 m (50 ft) from trees, silos, and other small buildings is recommended. Recommended separation between large freestall buildings is greater than 23 m (75 ft).

Stowell and Bickert (1994) studied 16 barns in Michigan during summer conditions. They concluded those barns having large amounts of exposed open wall area per cow provided a more suitable thermal environment with less interior variation. Less desirable were six-row barns; long, poorly oriented barns; barns with less open wall area available per cow; and barns having an attached parlor or upwind obstruction.

An open ridge vent must also be present to maximize natural ventilation. Provide a minimum of 30.5 cm (12 in) of clear ridge opening for shelters up to 12 m (40 ft) wide with an additional 7.6 cm (3 in) of opening for each 3 m (10 ft) of shelter width beyond 12 m (40 ft) (Graves et al., 2006).

2.4: Cow Heat Stress Hours

Zulovich et al (2008) proposed a system by which to evaluate and optimize the operation of a heat abatement system. The concept of "Cow Heat Stress Hours (CHSH)" was proposed as a method to quantify the cumulative impact of heat stress conditions on lactating dairy cows. Cow Heat Stress Hours are calculated using the following calculation procedure:

1. Determine the THI for a given hour by using the average hourly ambient air temperature and relative humidity or dew point temperature along with a THI equation. If a facility is using evaporative cooling pads or fogger systems to pre-cool inlet air, the THI is based on the air conditions entering the barn from the pad or fogger system and not the ambient air conditions.
2. Determine the Cow Heat Stress Hours (CHSH) by using the following normalization procedure:
    - CHSH = THI – 70 when THI from step one is greater than or equal to 70.
    - CHSH = 0 when THI from step one is less than 70 and greater than 65.
    - CHSH = THI – 65 when THI from step one is less than or equal to 65.

2.4.1: Cow Heat Balance

The CHSH is used to provide a method to help manage heat abatement systems for lactating dairy cows. A quantitative method to access the heat balance of a lactating dairy cow is presented below.

$$CHB = \sum_{1}^{24} \text{CHSH} - (HAP_{am} * HRS_{fans}) - (HAP_{dc} * HRS_{spr}) - \sum_{1}^{24} \text{AXF} \qquad \text{Eq. 2.9}$$

Where:

CHB = Cow heat balance for a given 24 hour period

CHSH = Hourly Cow Heat Stress Hours as determined and defined in previous section

HAP_{am} = Heat Abatement Potential due to air movement

HRS_{fans} = Number of hours circulating or stir fans are operating during the 24 hour period

HAP_{dc} = Heat Abatement Potential due to direct sprinkler wetting of cows

HRS_{spr} = Number of hours sprinkler are operating during the 24 hour period

AXF = Air exchange factor of freestall barn for the hour corresponding to the CHSH

The Cow Heat Balance (CHB) can be completed for any 24 hour period that may be of interest. If one wants to use the CHB to better manage heat abatement systems on dairy operations, starting the summation at 9 AM in the morning and completing the summation at the 8 AM in the morning will provide an easy check to knowing whether or not the provided heat abatement components were adequate to adequately cool cows exposed to the conditions evaluated.

2.4.1.1: Heat Abatement from Air Movement (HAP_{am})

The benefits of air velocity are incorporated into the Cow Heat Balance using the Heat Abatement Potential due to air movement term (HAP_{am}), which is defined as follows:

- HAP_{am} = 0 when air movement at cow level is less than 0.4 m/s (80 fpm),
- HAP_{am} = 1 when air movement at cow level is 0.5 m/s (100 fpm),
- HAP_{am} = 2 when air movement at cow level is 1 m/s (200 fpm) or more.

Naturally ventilated freestall shelters can incorporate a HAP_{am} value only if supplemental circulation fans are installed and operating within a shelter.

2.4.1.2: Heat Abatement from Direct Cooling (HAP_{dc})

The Heat Abatement from Direct Cooling (HAP_{dc}) should only be used for shelters with direct evaporative cooling systems capable of producing droplet sizes large enough to penetrate through the hair coat of the cow and directly wet the skin of a cow. The HAP_{dc} = 1 for sprinkler systems located at feed alleys, and the HAP_{dc} =2 for sprinkler systems located at feed alleys with circulation fans located above the feed alley and incorporated with the sprinkler operation.

2.4.1.3: Impact of Air Exchange (AXF)

A freestall shelter with a delivered air exchange that is very high can improve thermal conditions within the freestall shelter; however a freestall shelter with an air exchange that is minimal will tend to make the cows feel warmer. The Air Exchange Factors (AXF) to be used in the above equation for various freestall shelter ventilation systems and designs are provided below.

For mechanically ventilated dairy shelters, the Air Exchange Factor (AXF) can be estimated as follows:

- AXF = 1 for mechanically ventilated barns during daytime hours
- AXF = -1 for mechanically ventilated barns during hot nighttime periods
- AXF = 0 for mechanically ventilated barns during warm nighttime periods

For naturally ventilated dairy shelters, the Air Exchange Factor (AXF) can be estimated using the following table:

Table 2.3. AXF for naturally ventilated shelters

	Small Sidewall Openings		Moderate Sidewall Openings		Large Sidewall Openings	
Ambient Temp	Poor	Good	Poor	Good	Poor	Good
< 70	-1	-1	0	1	1	2
70 – 85	-2	-2	-1	-1	-1	0
> 85	-2	-2	-2	-2	-2	-1

Notes: Large sidewall openings use at least 3/4 of the vertical sidewall height and most of the sidewall length. Moderate sidewall openings use at least 1/2 of the vertical sidewall height and more than 3/4 of the sidewall length. Small sidewall openings use less than 1/2 of the vertical sidewall height and less than 1/2 of the sidewall length. The “Poor” and “Good” columns relate to the orientation of the shelter with respect to prevailing summer wind currents. A “Good” orientation aligns the shelter such that most summer wind currents are close to perpendicular to the sidewall opening. A “Poor” rating is for a shelter where a significant portion of the summer winds do not align with sidewall openings.

2.4.2: Application of Cow Heat Stress Hours (CHSH)

Zulovich et al (2008) performed an analysis of heat stress potential for Defiance, Ohio using August 2005 weather data. The affect of turning on the sprinklers when the dry bulb temperature was 21ºC (70ºF) instead of 24ºC (75ºF) on month cow heat balance was determined. The month total cow heat balance is the sum of the daily cow heat balance. When the sprinklers are not turned on until 24ºC (75ºF), the number of monthly heat stress hours is estimated to be about 13 times the hours when the sprinklers are turned on at 21ºC (70ºF). In this example, if direct evaporative cooling heat abatement measures had been implemented earlier, at a lower temperature, the total Heat Stress Hours would have been lowered by 294.5 hours or 92%.

Table 2.4. Example use of Cow Heat Balance (CHB)

	Monthly CHB
Normal THI	1291.8
Fan on at 21C (70ºF)	562.3
Sprinkler on at 24ºC (75ºF)	319.5
Sprinkler on at 21ºC (70ºF)	25.0

Chapter 3:

Objectives

While much research has been done on the various aspects of dairy heat abatement systems, as described in Chapter 2, the data and results are scattered throughout the literature. Design and performance data from these systems has never been combined into a single source documenting the effectiveness of the heat abatement systems.

The overall objective is to provide information to dairy producers, professionals, and advisors concerning heat abatement options that will aid them in making decisions as to which system will work best given their present or planned facilities and management. The focus will be limited to dairies in the Northeast and Midwest climates.

Specific objectives are:

1) A critical review and interpretation of heat abatement techniques in the US.

2) Development of the basic outline of a decision aid or "tool" to assist in the selection of a heat abatement technique for a specific dairy.

3) Design recommendations for heat abatement techniques, facility design, and operation applicable to the Northeast dairy industry.

Chapter 4:

Methodology

Published research data of results and effectiveness of various heat abatement techniques along with the design information will be compiled. Interpretation of this data along with field experience and observations will be used to develop recommendations as to the applicability of these systems to the Northeast dairy industry.

Tables with qualitative attribute of each system will be constructed.

Table 4.1. Example of qualitative attributes

	Cooling Effectiveness	Ability to maintain air speed at animal level	Water usage
Tunnel ventilation			
Circulation fans			
HVLS			
Cooling pads			
Foggers			
Sprinklers			

Both capital and operational cost comparisons are highly dependent on the type and size of the barn and the number of animals housed. One possible way to look at this would be to develop a series of tables comparing two options versus the number of animals housed and use some standard costs for fans and electric. Example tables are shown below.

Table 4.2. Example of capital cost for tunnel ventilation vs. circulation fans in a 6 row freestall.

Based on costs of $x per circulation fan and $y per tunnel fan

Number of cows	Tunnel Ventilation	Circulation fans
100		
200		
300		
400		
500		
600		
700		

Table 4.3. Example of operational costs for tunnel ventilation vs. circulation fans in a 6 row freestall.

Based on z cents per kW-hr of electric and t hours of on time.

Number of cows	Tunnel Ventilation	Circulation fans
100		
200		
300		
400		
500		
600		
700		

Chapter 5:

Heat Abatement System Selection Tool

A heat abatement system must provide the four basics 1) shade, 2) air exchange, 3) air speed to maximize convective cooling, and 4) evaporative cooling if needed. If one assumes adequate shade is provided by the shelter itself then the process for further selection of heat abatement system components has 3 steps: 1) selection of an air exchange method, 2) selection of a method to increase air speed, and 3) selection of an evaporative cooling method.

The selection of heat abatement system components must consider not only the physical design, but must also weigh the capital and operational investment against the estimated return in production and increased herd health. Also when the system is to be retrofitted into an existing facility, there may be other limitations of the present facilities that need to be included in the selection process.

Air exchange is the fundamental basis of any ventilation system, either summer or winter conditions. Therefore the emphasis of the above design approach is to start with good air exchange in a shelter and build from there. Additional convective and evaporative cooling should not be considered until the air exchange requirements of the shelter have been met.

Following are decision trees for making the choice of a heat abatement system a logical procedure. The first decision tree assists in the evaluation of the air exchange of the shelter and the possible need for additional convective cooling. Once these issues have been addressed then the second tree assists in the evaluation of the need for and selection of an evaporative cooling system. Each decision is further discussed in the text that follows. These are meant as an aid in formalizing the selection procedure. Due to the individuality of dairy design, additional references may need to be used in the final design of the system.

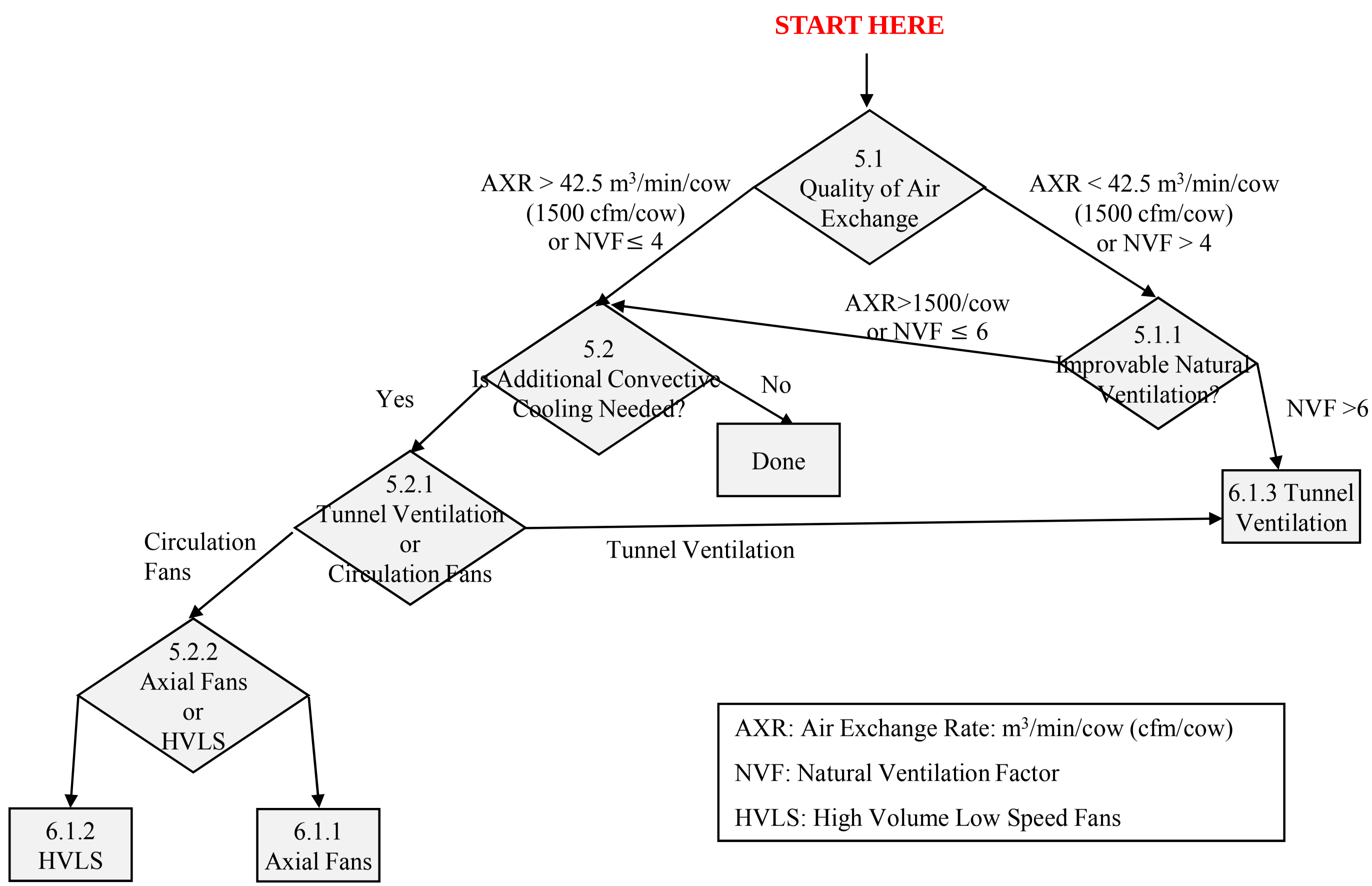

Figure 5.1. Decision tree for evaluation of air exchange and convective cooling.

The numbers refer to sections in Chapter 5 and 6. Diamonds denote where decisions will need to be made while squares refer to design information in Chapter 6.

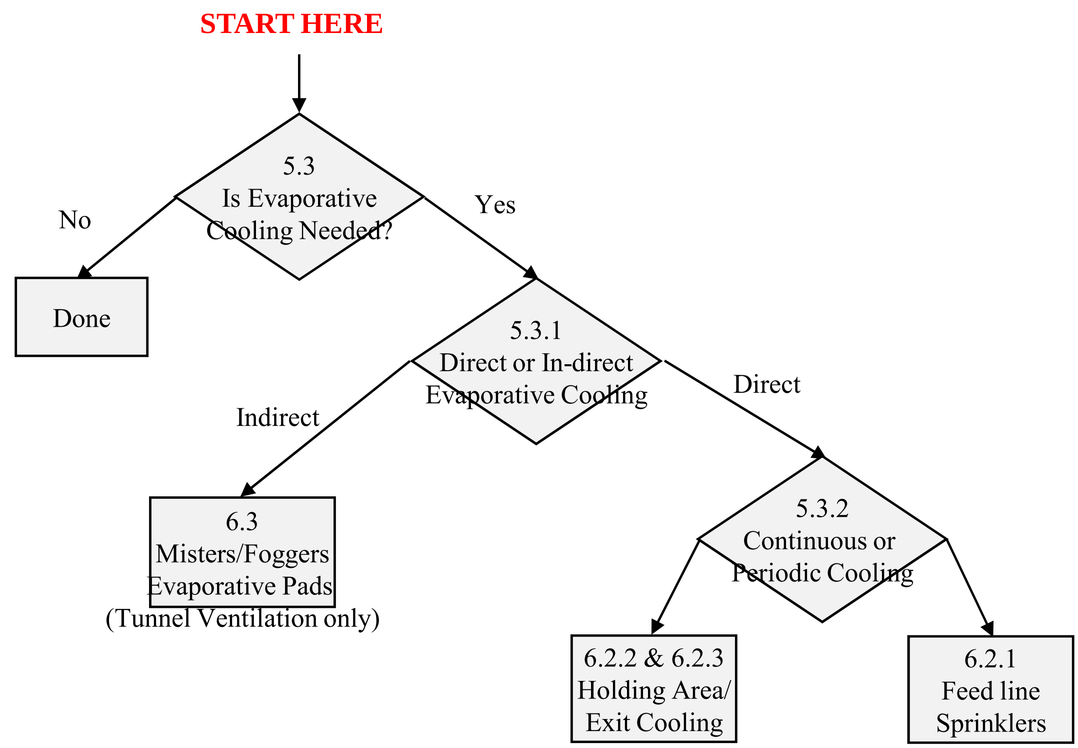

Figure 5.2. Decision tree for evaluation of the need for and selection of an evaporative cooling system.

5.1: Quality of Air Exchange

The first step to selection of a heat abatement system is to evaluate the air exchange ability of the structure. Air exchange can be achieved by two methods; mechanical or natural ventilation. Evaluation of a mechanical system is quite easy. Simply add together the total fan capacity of the shelter and divide by the number of animals housed. The goal for summer would be to provide at least 42.5 m^3/min (1500 cfm) per animal of air exchange (Bucklin et al., 1991; MWPS, 2000; Stowell et al., 2003; Tyson et al., 2004). If less than 28.5 m^3/s (1000 cfm) per animal of air exchange is present, then conditions within the shelter during hot weather will suffer. Also verify that the inlet area is adequate and properly located for given fan capacity. A minimum total inlet area of 0.23 m^2 per 28.5 m^3/min (2.5 ft^2/1000 cfm) of fan capacity should be provided. If needed, additional inlet area should be provided before adding additional fans to the system.

To evaluate adequacy for natural ventilation potential use the following three criteria: ventilation openings, shelter orientation to prevailing winds, and shelter exposure to winds. Ventilation openings consist of the effective sidewall opening per cow (A_c) and the ridge opening (R_o). The following equation can be used to calculate A_c for a given shelter.

$$A_c = H_e L_e / C_n \qquad \text{Eq. 5.1}$$

Where:

A_c = Effective windward sidewall opening area per cow

H_e = Effective wall opening height of the building (shelter eave height minus obstructions such as stall base, header, screen, curtain hardware, etc.)

L_e = Effective length (shelter length minus posts, curtain hardware, stalls, doors, other buildings, etc.)

C_n = Number of cows in the shelter

The following table can be used to objectively evaluate the potential natural ventilation of a given facility.

Table 5.1. Qualitative evaluation of the natural ventilation factor (NVF).

Risk Factor	**Best (1)**	**Medium (2)**	**Poor (3)**
Ventilation openings (Stowell and Bickert, 1994)	$A_c > 1.0$ m^2 /cow (11 ft^2 /cow) **AND** $R_o > 7.6$ cm per 3 m of shelter width (> 3 in/ 10 ft)	A_c between 0.65 m^2 and 1.0m^2 /cow (7 ft^2 to 11 ft^2 /cow) **AND** R_o between 5.0 cm and 7.6 cm per 3 m of shelter width (between 2 in and 3 in per 10 ft)	$A_c < 0.65$m^2 /cow (7 ft^2 /cow) **AND** $R_o < 5.0$ cm per 3 m of shelter width (< 2 in/ 10 ft)
Orientation to prevailing winds (Hellickson et al., 1983)	Shelter perpendicular to prevailing summer winds	Shelter diagonal to prevailing summer winds	Shelter parallel to the prevailing summer winds
Exposure to winds (Hellickson et al., 1983)	Smooth terrain such as smooth open ag fields	Scattered trees and small buildings upwind	Rough terrain with tall trees buildings and/or embankments

Evaluate the facilities for each one of the three criteria giving a “risk factor” of 1 thru 3 for each criterion. Then add the three risk factors together to arrive at a total natural ventilation factor (NVF) for the facility. If the total is less than or equal to 4 the building could provide good quality natural ventilation, if total is 5 to 7 the building’s natural ventilation is compromised, and if 8 or greater the building’s natural ventilation is greatly compromised and perhaps alternative methods for ventilation should be explored.

5.1.1: Improvable Air Exchange

For those structures with a NVF of 5 to 7 perhaps the natural ventilation characteristics can be improved. Orientation of an existing building cannot be altered. Therefore the two criteria to look at are wall opening and exposure. Often changing exposure is also limited, but there may be small trees, other unused buildings, hay storage, or machinery that could be removed to increase the exposure. The most often improvable criterion is the sidewall and endwall openings and whether they can be increased by removing obstructions such as siding. Recalculating the effective opening per stall due to proposed modifications will determine if the ability to naturally ventilate the structure is improved.

Due to the variability of wind direction, endwall openings are also very important. While the use of roller doors is inexpensive they can limit the maximum effective opening. Consider the use of overhead doors, stacking roller doors, or complete curtain endwalls. Gable endwall openings can help poorly oriented barns maintain comfortable conditions regardless of wind direction.

Figure 5.3. Endwall curtain on natural ventilated freestall shelter.

Figure 5.4. Gable end curtain on natural ventilated freestall shelter.

However, the amount of opening is not always as it seems. Due to structural components and screening the effective opening can be reduced by a much as 50%. Sidewalls should be able to be completely opened from the eave to the freestall surface. When using curtain support screen select one made with thin metal wire to give a larger effective opening. Also be very careful about how stalls, curtain hardware, and non-structural components are mounted so as not to block the opening. Mount outside freestalls on narrow steel channel or individual posts to minimize blockage of the inlet. Minimize the size of non-structural dimensional lumber used to mount curtains and other hardware. Also minimize non-essential components mounted in the wall opening.

If the natural ventilation factor cannot be improved to less than or equal to 6 then tunnel ventilation may be the best option for this structure. If the risk is less than or equal to 6 than acceptable air exchange is possible with natural ventilation.

5.2: Additional Convective Cooling

After air exchange has been maximized the next step to reach additional heat abatement is to increase the convective cooling ability of the cow. The Cow Heat Balance model developed by Zulovich, et al. (2008), described in section 2.4, can be used at this point to help determine the need for additional cooling. By looking at local weather data you can objectively get an idea of how severe heat stress may or may not be on your farm.

In the Northeast United States the worst period of time for heat stress is typically between mid July thru mid August. Therefore this time period is the worst case scenario to design for in heat abatement. The goal would be to have a cow heat balance of zero over any 24 hour period and definitely for any 48 hour period during this time. Additional convective cooling, i.e. air speed greater than 1.0 m/s (200 fpm), could possibly lower the cow stress hours by approximately 2 for each hour of use. The next question is then how to best do this in a given shelter.

5.2.1: Circulation Fans vs. Tunnel Ventilation

Gooch and Stowell (2003) reported finding little to no difference in the heat abatement achieved between freestall facilities using either tunnel ventilation or well designed natural ventilation with axial circulation fans. Because of this, one area that can assist a producer in making the decision is to compare the capital cost of fans between the two systems to aid in making the decision.

In general, when the capital cost for fans is compared, longer (i.e. larger) barns show an advantage to tunnel ventilation. This is due to the fact that tunnel ventilation is based primarily on the cross section of the barn and is not influenced by the total length. If a typical six row freestall barn is 36.5 m (120 ft) wide with a 4.3 m (14 ft) eve height, the “critical length” is approximately 150 m (500 ft) where the capital cost of tunnel ventilation fans becomes less than that of circulation fans.

The second item to consider is the operational costs of the system. The largest portion of this is electricity. Once again, larger barns will show an advantage to tunnel ventilation due to fewer and often more efficient motors, leading to less total electricity usage per hour of operation.

However, total hours of use of both systems will not be the same. During a cooling season a tunnel system tends to run more hours than a circulation system. Tunnel ventilation has the disadvantage of not being able to be staged, like circulation systems, as the weather warms up. When the sidewalls are closed to begin tunnel ventilation all the fans must be run to achieve the correct air exchange within the shelter. Meanwhile, a circulation system can be staged to add additional convective cooling as needed during spring and fall as the day time temperature raises. A tunnel ventilation system could be automated to drop the curtains and shut off fans during cool nights as long as air exchange is maintained with the natural ventilation system. Each farm needs to estimate their hours of usage of each system for better evaluation.

Below several tables have been developed to compare the capital and operational costs of tunnel ventilation (TV) and natural ventilation with supplemental axial circulation fans (NVSF) for various freestall shelter configurations and sizes. The basic design and cost assumptions used are as follows:

- Tunnel ventilated shelters designed for air speed of 2.5 m/s (500 fpm) or 42.5 m^3/min/cow (1,500 cfm/cow). The larger of the two is used.
- Tunnel ventilation fans used are 708 m^3/min (25,000 cfm) per fan, consume 1.2 kW·h/hr of operation, and cost $1,200 per fan

- Supplemental circulation fans are spaced 10 times their diameter at 12 m (40 ft) on center over all rows of freestalls and the feed line, consume 1.0 kW·h/hr of operation per fan, and cost $475 per fan

To estimate yearly operation costs a total number of hours of operation per year for each system needed to be estimated. The following management schemes were used for the TV and NVSF systems:

- TV was operated when the temperature was ≥15.5°C (≥60°F).
- Three stages of NVSF were used:
  - 1/3 of fans in operation at temperature ≥15.5°C and <18°C (≥60°F and <65°F)
  - 2/3 of fans in operation at temperature ≥18°F and <20°C (≥65°F and <68°F)
  - all fans in operation at temperature ≥20°C (≥68°F)

Hourly weather data from January 1, 2001 through December 31, 2005 for Selinsgrove, PA was then used to estimate the following operational hours. It was felt this location would be representative of Central Pennsylvania. When this method is used to assist in the design of a heat abatement system outside Central PA, more localized weather data should be used.

Table 5.2. Average hours per year in a given temperature range. (Selinsgrove, PA)

Temperature Range	Hours per year
Temperature ≥15.5°C (≥60°F)	3100
Temperature ≥15.5°C and <18°C (≥60°F and <65°F)	800
Temperature ≥18°F and <20°C (≥65°F and <68°F)	300
Temperature ≥20°C (≥68°F)	2000

Table 5.3. Capital and Operational cost comparison of tunnel ventilation vs. natural ventilation with axial circulation fans for various size three row freestall shelters with inside feeding.

Stalls	Capital Cost of Fans		Hourly Power Usage (kW·h/hr)		Yearly Power Usage (kW·h/yr)†	
	Tunnel Fans	Circulation Fans (4 rows)	Tunnel Ventilation	Circulation Fans	Tunnel Ventilation	Circulation Fans
100 stalls 4.3 m x 20.7 m x 51.2 m (14'x68'x168')	13,500 m^3/min total (476,000 cfm total) 20 fans $24,000	16 fans $7,600	24 kW·h/hr	16 kW·h/hr	74,400 kW·h	39,500 kW·h
200 stalls 4.3 m x 20.7 m x 97.5 m (14'x68'x320')	13,500 m^3/min total (476,000 cfm total) 20 fans $24,000	32 fans $15,200	24 kW·h/hr	32 kW·h/hr	74,400 kW·h	78,900 kW·h
300 stalls 4.3 m x 20.7 m x 145 m (14'x68'x476')	13,500 m^3/min total (476,000 cfm total) 20 fans $24,000	48 fans $22,800	24 kW·h/hr	48 kW·h/hr	74,400 kW·h	118,400 kW·h

†: values have been rounded to neared 100 kW·h

Table 5.4. Capital and Operational cost comparison of tunnel ventilation vs. natural ventilation with axial circulation fans for various size six row freestall shelters.

Stalls	Capital Cost of Fans		Hourly Power Usage (kW·h/hr)		Yearly Power Usage (kW·h/yr)†	
	Tunnel Fans	Circulation Fans (8 rows)	Tunnel Ventilation	Circulation Fans	Tunnel Ventilation	Circulation Fans
200 stalls 4.9 m x 36.6 m x 51.2 m (16’x120’x168’)	27,184 m^3/min total (960,000 cfm total) 40 fans $48,000	32 fans $15,200	48 kW·h/hr	32 kW·h/hr	148,800 kW·h	78,900 kW·h
400 stalls 4.9 m x 36.6 m x 97.5 m (16’x120’x320’)	27,184 m^3/min total (960,000 cfm total) 40 fans $48,000	64 fans $30,400	48 kW·h/hr	64 kW·h/hr	148,800 kW·h	157,900 kW·h
600 stalls 4.9 m x 36.6 m x 145 m (16’x120’x476’)	27,184 m^3/min total (960,000 cfm total) 40 fans $48,000	96 fans $45,600	48 kW·h/hr	96 kW·h/hr	148,800 kW·h	236,800 kW·h
1000 stalls 4.9 m x 36.6 m x 244 m (16’x120’x800’)	42,475 m^3/min total (1,500,000cfm total) 60 fans * $72,000	160 fans $76,000	72 kW·h/hr	160 kW·h/hr	223,200 kW·h	394,700 kW·h

†: values have been rounded to neared 100 kW·h
*: tunnel ventilation capacity based on animal numbers for exchange rate

Table 5.5. Capital and Operational cost comparison of tunnel ventilation vs. natural ventilation with axial circulation fans for various size four row freestall shelters.

Stalls	Capital Cost of Fans		Hourly Power Usage (kW·h/hr)		Yearly Power Usage (kW·h/yr)†	
	Tunnel Fans	Circulation Fans (6 rows)	Tunnel Ventilation	Circulation Fans	Tunnel Ventilation	Circulation Fans
200 stalls 4.9 m x 31.7 m x 87.8 m (16’x104’x288’)	23,560 m^3/min total (832,000 cfm total) 34 fans $40,800	48 fans $22,800	40.8 kW·h/hr	48 kW·h/hr	126,500 kW·h	118,400 kW·h
400 stalls 4.9 m x 31.7 m x 152.4 m (16’x104’x500’)	23,560 m^3/min total (832,000 cfm total) 34 fans $40,800	78 fans $37,050	40.8 kW·h/hr	78 kW·h/hr	126,500 kW·h	192,400 kW·h
600 stalls 4.9 m x 31.7 m x 228.6 m (16’x104’x750’)	25,485 m^3/min total (900,000 cfm total) 36 fans * $43,200	114 fans $54,150	43.2 kW·h/hr	114 kW·h/hr	133,900 kW·h	281,200 kW·h
1000 stalls 4.9 m x 31.7 m x 343.8 m (16’x104’x1128’)	42,475 m^3/min total (1,500,000 cfm total) 60 fans * $72,000	174 fans $82,650	72 kW·h/hr	174 kW·h/hr	223,200 kW·h	429,300 kW·h

†: values have been rounded to neared 100 kW·h

*: tunnel ventilation capacity based on animal numbers for exchange rate

5.2.2: Axial Fans vs. HVLS

If the decision is made to use circulation fans then the next question is what type of fan to use. Circulation fans can be placed in natural ventilated freestalls shelters to increase the air velocity felt by the animals. The air speed goal should be to provide approximately 2.2 m/s (433 fpm) of air speed at cow level in the freestall areas and at the feed line. These two areas are where cows spend approximately 75% of their time and therefore are the most important.

Two types of circulation fan systems available are “conventional” high speed axial fans mounted perpendicular to the freestalls and feed line or high volume low speed (HVLS) fans located high above the freestall floor. When conventional axial fans are positioned over the freestalls and feed line they should be spaced at approximately 10 times their diameter (Bottcher et al., 1995a; Bottcher et al., 1995b) and mounted 2.2 to 2.4 m (7 to 8 ft) above the floor to minimize interference with cows and equipment.

Based on several studies and field observations, it seems the placement of HVLS fans is the most important criteria in the success of these systems. The fans perform better when located more over the animal resting area rather than the feed delivery area. HVLS fans form a large cylinder of air downward from the blades. As the air strikes the floor it then travels horizontal away from the fan. So to get this air in the cow area the fans are best placed above the cow area. Therefore the location of structural components of the barn such as posts and ceiling height must be considered when evaluating the usefulness of HVLS fans.

Spacing of HVLS fans seems to be best at approximately two times their diameter (Bottcher et al., 1998; Kammel et al., 2003). This spacing will maximize the air speed between the fans. As an example a three row freestall approximately 15.8 m (52 ft) wide could be covered by a single row of 7.3 m (24 ft) HVLS fans located every 15.2 m (50 ft) along the centerline of the barn. When used in wide drive through barns HVLS fans seem to work best when shifted from the feed driveway to be more over the stall area. However, to do this the location and placement of fans and structural posts must be taken into consideration at the time of shelter design.

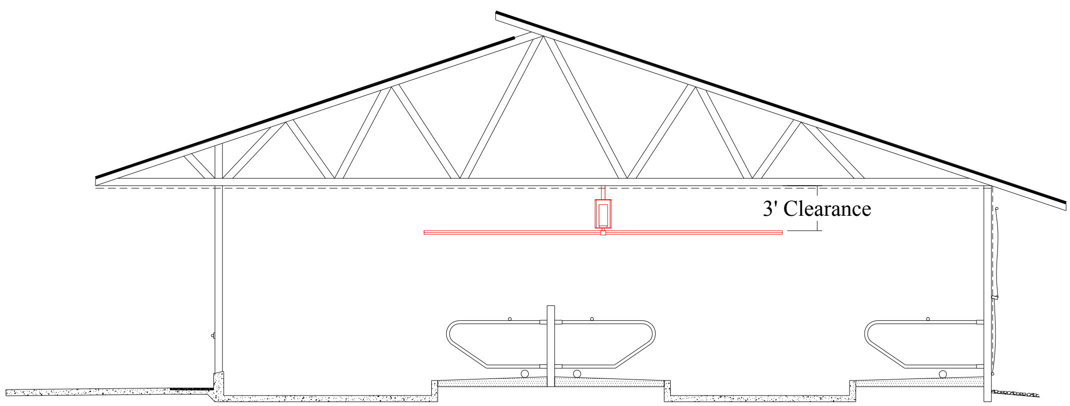

Figure 5.5. Clear span three row freestall shelter with HVLS fans.

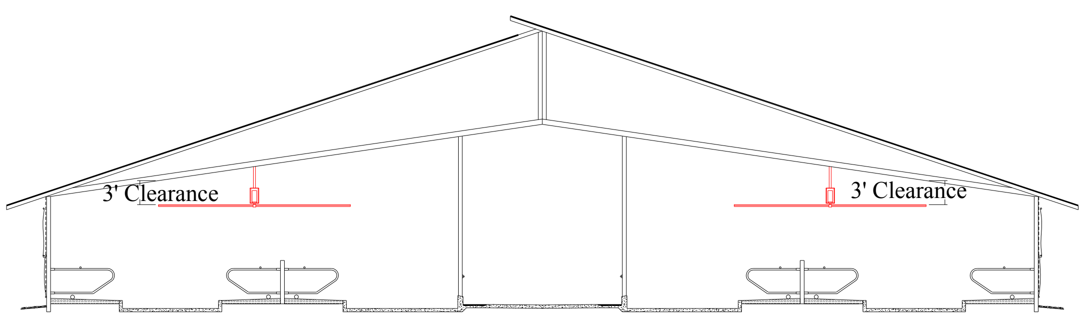

Figure 5.6. Six row freestall shelter with open area above freestalls for placement of HVLS fans.

Another concern with HVLS fans is the clearance between the fan blades and the ceiling or support structure of the barn. It has been observed that during periods of high natural winds the blades may contact the lower cord of the truss. Producers have made this observation and during periods of high wind may turn off the fans to avoid damage to the fan or building structure.

While HVLS fans can achieve air speeds of 1.0 to 1.5 m/s (200 to 299 fpm) at animal level this air speed is less than the optimum of 2.2 m/s (433 fpm). Worley and Bernard (2005; 2006) concluded that air speeds while more uniform throughout a 30.5 m (100 ft) wide 4 row freestall barn, were significantly lower in critical areas with HVLS fans as compared to conventional axial fans.

Comparison of capital costs to install and operational energy costs should also be done to help select between the two systems. As an example PSU Dairy Idea Plan Number 203 was used (Graves et al., 2006). This plan is a 47.5 m (156 ft) long by 15.8 m (52 ft) wide three row freestall shelter with 87 stalls. Using 127 cm (50 in) axial fans spaced approximately 12 m (40 ft) apart over each of the three rows of stalls and the feed line would require sixteen 127 cm (50 in) fans each with a 1 HP motor with electric consumption of 1kW. Using 7.3 m (24 ft) HVLS fans spaced approximately 15.2 m (50 ft) apart down the centerline of the barn would require three fans each with a 2 HP motor consuming 2 kW. Therefore power consumption for the axial system and the HVLS system are 16 kW and 6 kW, respectively. While this is a 63% savings in power the payback would depend on the capital cost difference of the systems. From field observation HVLS systems can cost two times or more that of conventional axial fan systems, but is also dependent on the access to competitive HVLS dealers in the area.

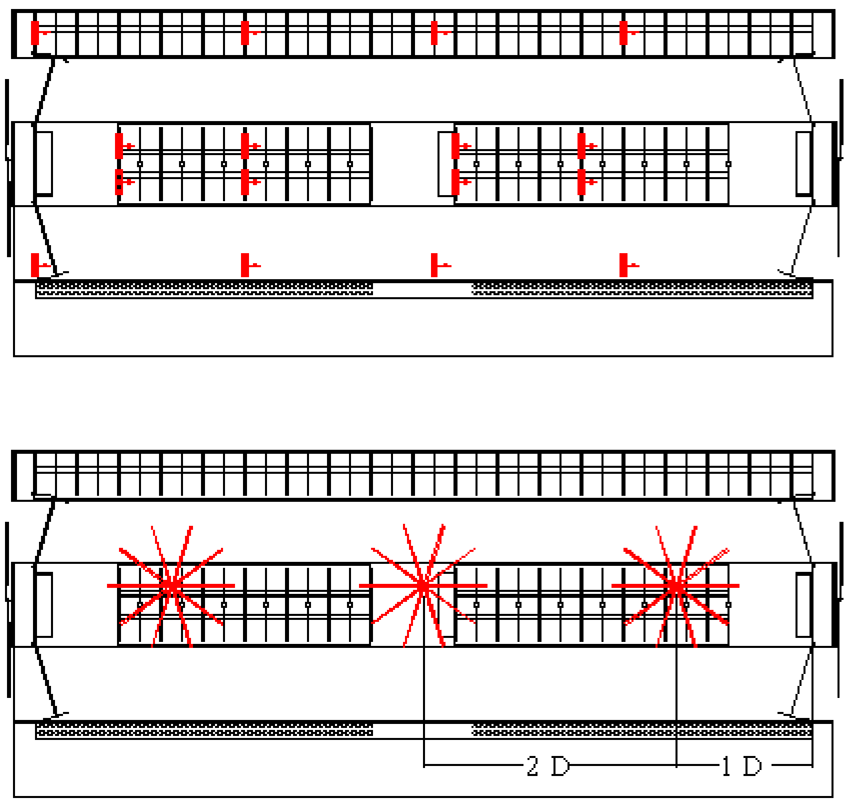

Figure 5.7. Plan view of three row barn with axial fans vs. HVLS fans.

5.3: Additional Evaporative Cooling

Heat stress conditions in much of the Northeast United States require additional evaporative cooling for optimum milk production and breeding efficiency. While added convective cooling may help postpone heat stress, once the animals reach the point of heat stress convective cooling alone may not be enough. Therefore adding some type of evaporative cooling to dairy housing in the summer is warranted. Once again the Cow Heat Balance model can be used to evaluate the need for evaporative cooling.

5.3.1: Direct or In-direct Evaporative Cooling

Evaporative cooling can be divided into two main types, direct or indirect. With indirect cooling the ambient air temperature is lowered and then circulated around the animal to increase convective cooling. In naturally ventilated shelters this can be done by injecting a mist or fog of water into the air stream directly in front of the circulation fans. This mist is usually created by a series of high pressure nozzles mounted directly in the fan housing. The cost is dependent on the size of the structure, because high pressure water lines must be run and maintained to all fans in the shelter. Maintaining these nozzles so as not to drip on stall beds has been a concern of producers over the years. To address this some have decided to only install nozzles on fans located away from the stalls; however this means that only part of the barn can be cooled.

In mechanically ventilated shelters (i.e. tunnel ventilated) indirect cooling can be isolated to the inlet end of the barn. If using a fogging system this means that the amount of high pressure pipe can be reduced. The goal in this system would be to evaporate as much water as possible as fast as possible so the cooler air can be drawn through the remainder of the barn. However, the shorter the barn, the larger the evaporation section becomes vs. the remainder of the barn and at an extreme the coolest air is at the exhaust fans. The challenge with fogging or misting systems seems to be getting the water that is being introduced into the air stream to completely evaporate before it either settles on surfaces in the barn or is exhausted by the fans. Once again the longer the shelter the more time and space is available to evaporate water and the more shelter and cows downstream from this point that benefit from the cooler air. For example if 18.3 m (60 ft) of barn is needed to introduce the water and the total length is only 36.6 m (120 ft) that means only half of the cows get total benefit from the system. However, if the barn was 73.2 m (240 ft) long then 75% of the animals get full benefit of the system.

The other option for indirect cooling in tunnel ventilated shelters is evaporative cooling pads. Once again water is evaporated by entering air lowering the ambient temperature and raising the humidity. However, in this system air is drawn in through a "pad" which water is cascaded over. The air evaporates the water as it passes through the pad; extra water is then re-circulated over the pad. Efficiency of evaporative pads ranges from approximately 68% to 85% dependent on the air speed through the pad. As speed increases the efficiency decreases, because the air has less time to evaporate water.

While raising the relative humidity, both misting and evaporative pad systems can lower both the ambient temperature and THI of incoming air. For example at 29.4°C (85°F) and 50% relative humidity the THI is 77.6. A 70% efficient indirect evaporative cooling system would condition the air to 23.6°C (74.5°F) at 84% relative humidity with a THI of 73. However, McFarland (2006) reported better cooling characteristics and less moisture problems with the use of evaporative cooling pads in conjunction with tunnel ventilation in tiestall facilities in Southeastern Pennsylvania vs. fogging systems.

The other major evaporative cooling type is direct cooling. It differs from indirect cooling in that the main objective is to wet the animal to the skin. To wet the cow's skin Chastian and Turner (1994) recommended the application of 1.2 L/m^2 (0.3 gal/ft^2) of water to the dorsal surface. Care must be taken in direct cooling systems to wet the skin and not just cover the animal with a fine layer of water on top of the hair, thus trapping a layer of air between the skin and water film effectively insulating the cow and maybe increasing the heat stress.

The most popular system of direct cooling is to wet the cow while she stands at the feed line with low pressure, higher volume, large droplet sprinklers. Typical nozzle specifications are 2.27 lpm (0.6 gpm) at 138 kPa (20 psi) spaced approximately 2.1 m (7 ft) on center and approximately 2.1 m (7 ft) above the floor (Harner III et al., 1999). Sprinklers are cycled on and off to allow the cow to "dry" between applications of water. Typical timing is 2 to 3 minutes on and 5 to 15 minutes off. That interval is shortened as ambient air temperature rises. Assuring good air exchange when using direct evaporative cooling is critical in making sure the extra moisture is removed from the shelter.

An estimate of the water quantity needed by a feed line sprinkler system can be made using the following equation:

$D_{WU} = F_L \times C_H \times H \times 1.86$ L/m (0.15 gal/ft)

Where:

D_{WU}= Daily Water Usage, liters (gallons)

F_L= Total Feed Line Length, meters (feet)

C_H= Cycles per Hour

H= Hours of Operation per day

Note: 1.86 L/m (0.15 gal/ft) represents the application of 1.2 L/m^2 (0.03 gal/ft^2) to a strip 1.5 m (5ft) wide along the entire feed line.

The largest drawback to direct evaporative cooling at the feed line is the large amount of water that potentially may be added to the manure system. Considerations must be given to the runoff produced by unused water that is either not applied to a cow or does not soak into the cow's hair coat when a feed line sprinkler system is designed. Field observations would suggest approximately 50% of the daily water usage of feed line sprinklers will be unused and become part of the daily manure production. To maintain cow cleanliness and milk quality the feed alley must be kept clean with frequent scraping. Freestall shelters with sloped alleys help avoid ponding of water in the alley and aid in scraping the thin manure. If a liquid manure handling system is in place in the freestall shelter the easiest way to handle runoff is to include it in to the normal manure system. However, the inclusion of runoff into the manure system will lessen the days of available storage. If additional manure treatment such as an anaerobic digester is present the awareness of this extra water must be included onto the manure treatment design. If a manure storage system is not present, than a runoff containment and/or treatment system will need to be developed for the freestall shelter.

However the payback can still be large. As an example, if half of the applied water is added to the manure system it would take only about 0.23 to 0.45 kg (0.5 to 1.0 lb) per cow of increased production to offset the added manure handling costs. If this added water is too much strain on the manure system perhaps an indirect cooling systems would be a better fit.

5.3.2: Continuous or Periodic Direct Cooling

Another option for using direct cooling while still conserving water is to cool cows "periodically" throughout the day by wetting cows only in the holding area and in the exit lane(s) while milking. Because the area covered is much less and more of the water will be placed on a cow the amount of water added to the manure system is much less. Studies have shown that the cooling effect of wetting cows at milking can last several hours after the treatment (Araki et al., 1985; Kendall et al., 2007). Thus for dairies milking three times per day this can greatly reduce the hours a cow's internal temperature is elevated during hot weather. Once more using the Cow Heat Balance model, and giving credit for evaporative cooling only during the milking times, the use of periodic cooling systems could be evaluated. However to achieve continuous cooling both feed line sprinklers and holding area/exit cooling needs to be used to guarantee that cooling is always available to the cow.

5.4: Selection Conclusion

There are many ways in which to cool cows in the Northeast United States. However, a producer and/or their advisors must use a logical approach to reach the proper selection of a system that best suits present and/or planned facilities and the management style of the farm. The following tables list the qualitative attributes of various heat abatement system components.

Table 5.6. Qualitative attributes of convective cooling heat abatement components.

	Cooling Effectiveness	**Ability to maintain air speed at animal level**
Tunnel Ventilation	Slightly lower daytime temperature than natural ventilated with circulation fans.	Non-uniform airspeed throughout shelter. “Channeling” must be addressed where air moves toward areas of less resistance and away from cows areas.
Circulation fans w/ air speed at 2.2 m/s	Marginal decrease in body temperature while standing and increase in body temperature while lying	Excellent if fans properly spaced and tilted
HVLS	Difficulty achieving and maintaining air speed of 2.2 m/s at animal level.	Uniformity of air speed dependent on proper spacing of fans.

Table 5.7. Qualitative attributes of evaporative cooling heat abatement components.

	Cooling Effectiveness	**Water Usage**
Indirect Evaporative Cooling (Cooling Pads or Foggers)	Lower air temperature 3°C to 5°C (5 °F to 9 °F)vs. outside.	Significantly less than feed line sprinklers. However, these systems are greatly influenced by ambient humidity of incoming air.
Direct Evaporative Cooling (Feed Line Sprinklers)	Rectal temperatures lowered at 0.5 to 0.7°C/hr (0.9 to 1.3°F/hr).	Varies widely dependant on management 216 to 456 L/cow/day (57 to 120 gal/cow/day) 50 to 60% of water applied typically leaves shelter in manure system.
Direct Evaporative Cooling (Holding Area and/or Exit Lane Cooling	Cows positively affected for several hours after treatment.	Lower water usage per cow per day and greater percentage applied to cow, therefore less goes into manure system vs. feed line sprinklers.

Chapter 6:

Design of Heat Abatement Components

Heat abatement is achieved through a three step process, assuming shade has been provided by the shelter itself. First the shelter air exchange needs to be optimized with either natural or mechanical ventilation. Once air exchange is optimized the second step is to increase the convective cooling rate of the animal by increasing air velocity at cow level. Circulation fans move the air already in the building providing convective cooling over the cow's body. The goal is to provide air velocity at cow level and penetrate the hair coat; air velocity at levels above cow level or at floor level will do little to aid the cooling of the cow. Circulation fans tend to be an addition to an already existing ventilation system such as natural ventilation. Tunnel ventilation also increases air velocity at cow level to improve convective cooling and also adds a controlled rate of fresh air exchange.

Thirdly some form of evaporative cooling can be added to the heat abatement system. Evaporative cooling can be added to a ventilation system to cool incoming air or in a separate approach to directly cool the cow with water applied to her body. Both natural ventilation with circulation fans, and mechanical ventilation (tunnel) systems can be outfitted with evaporative cooling to drop interior air temperature or directly cool the cow. Shelter design, construction, and management will, in part, dictate which type of heat abatement components can be successfully incorporated into the shelter.

While air conditioning of dairy housing shelters in theory could be used as a heat abatement method, it is felt at this time air conditioning is not an economically viable option. Therefore air conditioning will not be discussed in this thesis.

6.1: Convective Cooling of Cows

6.1.1: Axial Circulation Fans

The objective with circulation fans is to increase the convective cooling capacity of the cow. An air speed of at least 2.2 m/s (440 fpm or 5 mph) is desired at animal level. In order to do this fans are placed in rows perpendicular to the stalls and in freestall shelters may additionally be added along the feed line. Mounting height is most often 2.1 to 2.4 m (7 to 8 ft) above the stall surface or floor. Fans can be mounted higher if needed to allow equipment clearance, however fans will need to be tilted more to force the air down. Fan spacing should be 10 to 12 times the fans diameter; i.e. 9 m (30 ft) for 90 cm (3 ft) fans or 12 m (40 ft) for 120 cm (4 ft) fans. If fans are located too far apart "dead spots" with little or no air movement will develop between fans. A tilt angle of 15° to 20° from vertical is needed to push the air down to animal level. The goal would be to have the air stream from the first fan strike the freestall surface or floor under the second fan and so on down the length of the barn. To help in achieving the correct tilt angle imagine if you drew a line from the center of the first fan shaft, it should intersect the stall surface or floor under the next fan.

In freestall shelters while fans over both stalls and feed line is preferred, priority should be given to locating fans over the stalls if only a limited number of fans are going to be used. While locating fans at the feed line may encourage animals to come to the bunk, it may also encourage them to stand for long periods of time rather than lie down. Based on the simple fact that cows spent twice as much time during a 24 hour period lying as they do eating, locating fans over the stalls will provide cooling where cows spend the majority of their time.

Whether in a freestall or tiestall shelter, fans should be placed so the “center” of the air stream is traveling over the center of the cow. In an effort to maximize convective cooling the air speed must be maximized over the largest surface of the cow, which would be the area between the front shoulders and the rear hips. In tiestalls with limited headroom there may be a need to use smaller fans to work around obstructions such as the milk pipeline.

Figure 6.1. Axial circulation fans placed over the stalls.

Circulation fans can also be staged by ambient temperature to reduce operational costs. One method would be to turn 1/3 of the fans on at 16°C (60°F), 2/3 of fans by 18°C (65°F), and all fans by 20°C (68°F). Fans in the center of the shelter over the stalls, which is typically the area of “stalest air”, should be turned on first and then fans at the feed bunk and to the outer areas of the shelter second and third, respectively.

Proper maintenance of fans is needed to maintain the maximum air speed. Dirt on fans can reduce performance by 40% (MWPS, 1990). Fans should be cleaned at a minimum at least once per year in the spring before the hot weather season. Additional cleaning may be required if fans become dirty during the season. Operations using "dusty" bedding may see fans become dirty faster. Also all safety and protective guards should remain installed to prevent injury to cows or workers.

6.1.2: HVLS Circulation Fans

The goal with HVLS fans is the same as the axial fan objective: to increase the air velocity at cow level and thus increase the convective cooling of the animals. These fans have been shown to achieve an air speed of 1.0 to 1.5 m/s (200 to 300 fpm) over an area of approximately two times their diameter at a height of 1.5 m (5 ft) above the floor. While this is less than the desired air velocity, some benefit may be seen. Thus location and spacing of HVLS fans is critical to their success. Fans need to be located so the downward air column is over the stall area where cows are going to be located most of the day. These fans do little to aid in convective cooling of the cows when located over the center driveway of a large drive through freestall shelter. There is difficulty in locating HVLS fans around interior structure posts in drive through shelters, so they are best suited for clear span freestall shelters such as two and three row shelters. Spacing should be approximately two times the HVLS fan's diameter, i.e. 14.6 m (48 ft) on center for a 7.3 m (24 ft) fan. If considering HVLS fans in a new structure the ceiling height must be sufficient. As per manufacture recommendations, a ceiling height of 4.5 m (15ft) and blade clearance to ceiling/roof of 0.6 m (2 ft) is preferred for mounting these fans. When installed without proper clearance the fan blades could contact the barn structure during periods with high outside air speeds (i.e. storms) when the fan blade is wracked by wind currents. Before installation of HVLS fans it is recommended that a structural engineer be consulted about the impact of the additional load(s) of the fan(s) on the structure.

Figure 6.2. HVLS circulation fans located over stall area.

6.1.3: Tunnel Ventilation

Tunnel ventilation is a system composed of exhaust fans at one end of the shelter, an airflow path over the cows, inlets for fresh air entry at the other end of the shelter and some control for the transition into and out of tunnel ventilation mode. Sidewall and ridge openings of natural ventilated shelters must be closed during operation of the tunnel ventilation system. The shelter may be mechanically or naturally ventilated in times that tunnel ventilation is not used. Tunnel ventilation is most often a separate ventilation system from that which is used during cold and mild weather.

Tunnel ventilation air flow capacity is based on the cross sectional area (height x width) of the shelter and a desired air speed through that shelter. For a freestall shelter the design air speed should be 2.5 to 3.0 m/s (500 to 600 fpm), while in tiestall facilities the design air speed minimum is 1.5 m/s (300 fpm). The reason for the higher air speed in freestall shelters is that the air will “channel” or escape the cow-occupied area much easier due to the higher ceiling height and wider, more open alleys than seen in tiestall facilities. Air flowing above the cow level does not aid in convective cooling of the cows.

In an effort to minimize the air stream from escaping the cow level and simply flowing above their bodies, baffles are installed perpendicular to the air flow to force the moving air back down to the floor level. Installation of baffles also reduces the effective cross sectional area of the barn, by reducing the effective height, resulting in a reduction of tunnel ventilation installation and operating cost due to the need for less fan capacity. The baffles are constructed by simply covering the truss with a curtain material to force air flow down to the cow area. Field observations suggest that baffles should be installed approximately every 9 to 15 m (30 to 50 ft) along the length of the shelter. This baffle can be extended down below the bottom cord of the truss to the height of the feeding equipment if desired. Another option is to install a complete ceiling in the freestall shelter; however this is more costly than baffles and may affect the natural ventilation quality in non-tunnel ventilation weather conditions.

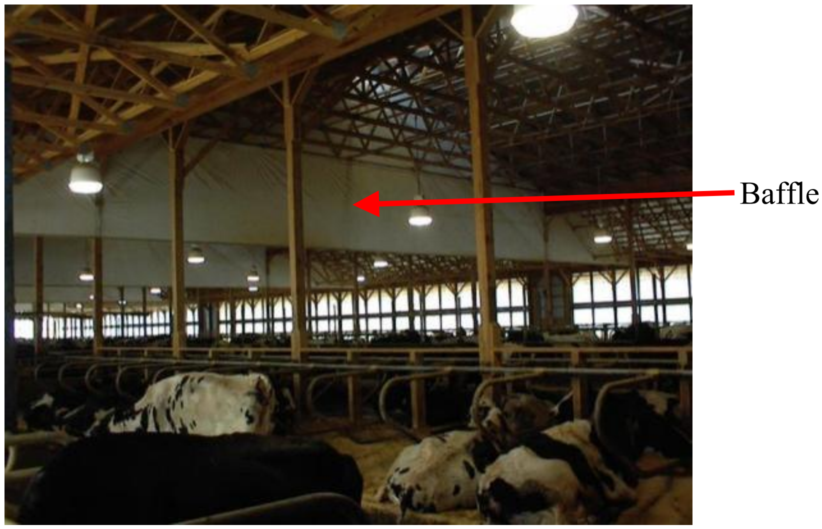

Figure 6.3. Baffles in a tunnel ventilated freestall to force air back down to cow level.

Another issue related to air flow preference is channeling of air away from the walls in freestall shelters with stalls located along an outside wall. Air speed measurements during field observations indicate that air speed in freestalls located along the outside wall is below the desired air speed. To address this issue two things can be done. First longer stalls of 3 to 3.4 m (10 to 11 ft) can be used as this allows air to travel along the length of the barn between the front of the stall and the wall. Secondly the bottom of the curtain can be opened 5 to 8 cm (2 to 3 in) to allow fresh air to enter the air stream at the cow's head; however this extra air must be compensated for with extra fans to ensure the overall air speed is maintained in the shelter. If evaporative cooling pads are used with tunnel ventilation, this bottom opening is not recommended as it allows preferential flow of uncooled air to enter the structure.

Figure 6.4. Using an extra long stall and providing an opening at the front of stalls along the outside wall to help improve air speed in the outside stalls.

To prevent airflow "dead spots" or wind shadows inside the shelter, interior obstructions such as solid walls should be avoided as much as possible. At the end of freestall rows, gates or fences should be used rather than solid plank or concrete walls. However, if waterers are located here it may be necessary to close the bottom half with a solid wall to avoid water being splashed into the stalls. Alternately center crossovers could be widened to 6 m (20ft) with the waterer located in the center to avoid water being splashed into the stalls. At end crossovers waterers should be located along the outside wall rather than the stall to minimize obstruction of air velocity near the cow.

Figure 6.5. Fencing is used in the cross over at the end of a freestall row.

Once the total tunnel ventilation capacity of the shelter is determined by multiplying the cross sectional area by the desired air speed, an air exchange check needs to be preformed to be sure that proper heat removal is supplied. Divide the total ventilation capacity by the cows to be housed in the facility and ensure that a minimum of 42.5 m^3/min (1500 cfm) per cow is being provided; if not the fan capacity should be increased to achieved this level of air exchange. To determine the number of fans required simply divide the ventilation capacity needed by the capacity of the individual fans selected at a static pressure of 12 Pa (0.05 inches of water). Select a fan design with high fan efficiency characteristics to minimize electric operational costs: 0.57 m^3/min (20 cfm) per watt minimum. Large tunnel ventilation fans typically have efficiency ratings ranging from 0.48 to 0.68 m^3/min (17 to 24 cfm) per watt. Higher efficiency fans have more expensive motor components, hence, the increased cost of manufacture, but pay back with savings in electrical operation costs. For a tunnel ventilation system needing 21,237 m^3/min (750,000 cfm) of fan capacity, using fans with an efficiency rating of 0.48 m^3/min (17 cfm) per watt rather than 0.57 m^3/min (20 cfm) per watt would increase electric usage by 6.6 kW or 17.6%. One source of fan data is to consult published Bioenvironmental and Structural Systems Laboratory (BESS) data for most commonly used agriculture fans (Ford et al., 2007).

Fan and inlet placement is the next design consideration. The goal is to create a wind tunnel with even air distribution along the entire cross sectional area of air flow. Best case scenario is to locate the inlet(s) in one endwall and all the fans in the opposite endwall of the shelter. However because of needed doorways this may not be completely possible. In that case placing all or most fans near the endwall, in the sidewall of the shelter, may be necessary. If fans are placed both in the endwall and sidewall, fans in the sidewall should be a minimum of 0.3 m (1 ft) from the endwall of the shelter. Fan placement has less effect on tunnel ventilation system performance than inlet placement will have. Tunnel ventilation airflow will be enhanced if moving in the same direction as prevailing summer breezes; i.e. avoid exhaust air directed into the wind. Consider the negative impact of warm, odorous exhaust air and the noise of fans near homes or areas used for outdoor recreation during warm weather.

The inlet area provided should be a minimum of 0.25 m^2 (2.5 ft^2) per 28 m^3/min (1000 cfm) of fan capacity. In large freestall shelters where the design air speed exceeds 2 m/s (400 fpm) the inlet area should be equal to the cross sectional area of the shelter plus 10-20% to account for obstruction to airflow within the inlet area (structural posts, bird netting, curtain hardware, etc.)

Placement of the inlet is critical in the performance of the tunnel ventilation system. The inlet area should be equally distributed and evenly matched on both sides of the shelter to achieve a uniform inlet air pattern.

Maintenance of the fans in a tunnel ventilation system is important to achieving maximum performance. Dirty fans and louvers can drop fan performance by as much as 40%. Therefore fans should be cleaned a minimum of twice per ventilation season, once at the beginning before starting and once during the tunnel ventilation season.

One problem with the use of tunnel ventilation as a hot weather system, as currently employed in dairy housing, is that it cannot be staged; it is either on or off. In an effort to stay out of heat stress the tunnel system should be on by 15.5°C (60°F).

However, with automatic controls of fans and curtains it would be possible to automate the switch back and forth during spring and fall when nights fall below 15.5°C (60°F).

6.2: Direct Evaporative Cooling of Cow Body

The goal with feed line sprinklers is to wet the cow to the skin with water and then use cow body heat to evaporate that water to provide direct evaporative cooling of the cow. The evaporation of 0.45 kg (1 lbs) of water requires approximately 1055 kilojoules (1,000 Btu's) of energy. The majority of that heat is acquired from the cow's body in direct cooling systems. In order to do this the cow needs to be wetted with a system that produces a large enough droplet size that can penetrate the hair coat in a short period of time, and then the sprinkler system needs to shut off and allow the cow to dry before the next wetting cycle is started. The degree of "dryness" that is wanted is somewhat a judgment call. As the skin and hair coat dry the amount of water available for evaporation decreases and thus the cooling effect decreases. The animal's hair should be dried to a point were no more free water is present, i.e. a towel would still be dry if rubbed over the animal. This drying time is typically 5 to 10 minutes dependent on ambient temperature, humidity, and air velocity at animal level. Sufficient air exchange for the shelter and air velocity at cow level is needed to aid in evaporation of the water from the cow and eventually removal from the shelter.

The animal must be soaked to the skin in order to achieve the evaporative cooling wanted. If the water droplets are too fine they will be trapped in the hair coat and not reach the skin. If trapped in the hair coat the water will act as an insulator and possibly increase the heat buildup in the animal causing more heat stress.

6.2.1: Feed Line Sprinklers

The design criterion to soak the animal to the skin is to apply 1.2 L/m^2 (0.03 gal/ft^2) of water to the 1.5 to 1.8 m (5 to 6 ft) area directly behind the feed line, which would cover the standing cow's dorsal surface from the front shoulder to rear hips, in a two to three minute time period (Chastain and Turner, 1994). This application rate equals 1.3 mm (0.05 inches) of water depth, or what would equate to a brief rain shower. The sprinkler system is then shut off and the cow allowed to dry before being soaked again. Care should be taken to not over-wet the cow and/or wet the udder. Once water begins to drip from the sides of the cow, no additional water is needed as it will not stay in the hair coat anyway. If this rule of thumb is followed no udder wetting should occur. As ambient temperatures increase the soaking interval (time between water applications) should be shortened to increase heat abatement. Starting the next wetting cycle before the animal is completely dry, allows for evaporative cooling to remain at a higher rate by keeping more water available for evaporation. One commonly used staging system is at ambient temperature greater than 21°C (70°F) one cycle every 15 minutes, greater than 27°C (80°F) one cycle every 10 minutes, and greater than 32°C (90°F) one cycle every 5 minutes (Brouk et al., 2003a). In freestall housing systems animals freely come and go to the feed line, therefore not all animals will be soaked with each application of water. Also after cows acclimate to the system they seem to be drawn to the sprinklers. Therefore by shortening the soaking interval during higher temperatures there are more opportunities for cows to be soaked and thus more cows are cooled by the system per hour.

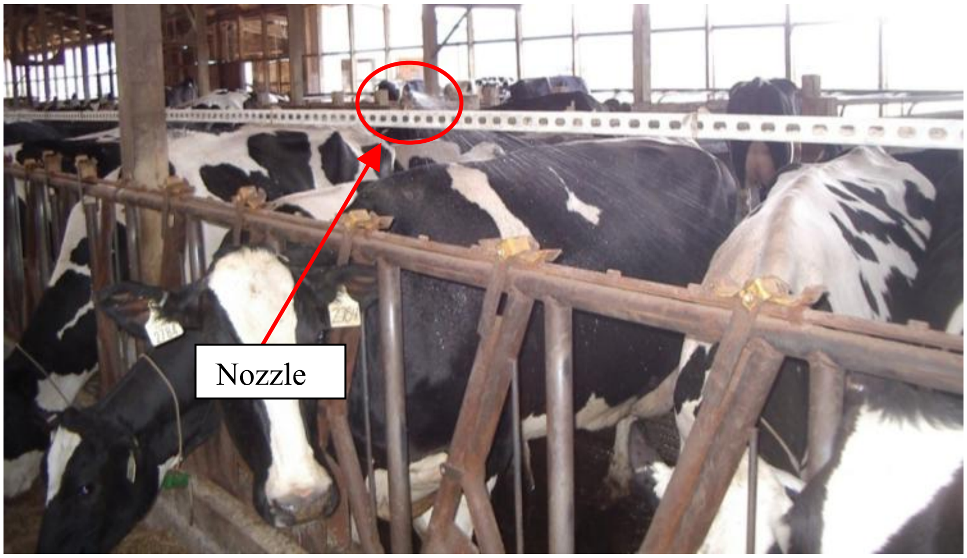

Figure 6.6. Feed line sprinkler system in use.

Figure 6.7. The animals are soaked to the skin at the feed line and then allowed to dry.

Height and spacing of nozzles is dependent on the type of nozzle selected. However, typical height would be 1.8 to 2.4 m (6 to 8 ft) above the feed alley floor, and typical spacing would be 1.8 to 3.0 m (6 to 10 ft) on center down the length of the feed line. The nozzles must be located and spaced to allow for even application of water from the front shoulder to the rear hips of the animals as they stand at the feed line.

To help in estimating the total daily water use of a feed line sprinkler system the following equation has been developed:

$D_{WU} = F_L \times C_H \times H \times 1.86$ L/m (0.15 gal/ft)

Where:

D_{WU}= Daily Water Usage, liters (gallons)

F_L= Total Feed Line Length, meters (feet)

C_H= Cycles per Hour

H= Hours of Operation per day

Note: 1.86 L/m (0.15 gal/ft) represents the application of 1.2 L/m^2 (0.03 gal/ft^2) to a strip 1.5 m (5ft) wide along the entire feed line.

As an example use Dairy Idea Plan Number 226 (Graves et al., 2006), a six row freestall shelter with 348 stalls in 4 groups which has a total of 185m (608ft) of feed line divided between 4 groups of 87 stalls each. If a feed line sprinkler is used for 10 hours per day with an average of 6 cycles per hour the daily water usage would be 20,646 L (5,472 gal), or 59.3 L/ cow (15.7 gal/cow).

The water supply needed to “keep up” with the sprinklers when they turn on must also be addressed. For the same example freestall shelter used above the water supply needed to provide wetting in 2 minutes would be 172 L/min (45.6 gpm) if the entire barn is sprinkled at one time. However, by dividing the barn into 4 zones, one for each group of 87 stalls, the water supply needed is cut to 43 L/min (11.4 gpm). Zoning greatly reduces the piping size needed as well as cutting the instantaneous water requirement.

However, the total water supply needed for operation of the sprinkler system remains the same. Installation of a water storage tank(s) for sprinkler use to act as a “buffer” to the instantaneous water needs is an option for farms with a limited water supply. If sprinklers are only needed for 10 to 12 hours per day the tank can be filled throughout the entire day at a slower rate and thus sprinklers may not interfere with other water needs on the farm such a parlor equipment washing. Piping needs for feed line sprinklers vary greatly from farm to farm, thus a qualified designer should be consulted for each specific sprinkling system.

Considerations must be given to the runoff produced by unused water that is either not applied to a cow or does not soak into the cow’s hair coat when a feed line sprinkler system is designed. Field observations would suggest approximately 50% of the water used by feed line sprinklers will not be applied to cows but rather will become part of the daily manure production. To maintain cow cleanliness and milk quality the feed alley must be kept clean with frequent scraping. Freestall shelters with sloped alleys help avoid ponding of water in the alley and aid in scraping the thin manure. If a liquid manure handling system is in place in the freestall shelter the easiest way to handle runoff is to include it in to the normal manure system. However, the inclusion of runoff into the manure system will lessen the days of available storage. If a manure storage system is not present, than a runoff containment and/or treatment system will need to be developed for the freestall shelter.

6.2.2: Exit Lane Soakers

In an effort to use less water than feed line sprinkler systems and avoid the additional water that would be added to the manure system some dairy operations have used sprinklers in the exit lane(s) of the parlor to soak cows as they return to the housing area. It has been shown in studies that this single cooling event will cool the cow for several hours before her body temperature returns to that of non-cooled cows (Araki et al., 1985; Kendall et al., 2007). In field observations cooling during return also seems to encourage animals to visit the feed bunk when they return to the shelter and thus may help to maintain dry matter intake during hot weather.

Because the opportunity time for wetting is only about two seconds while the cow walks a distance equal to her body length, the nozzle(s) must emit a high flow rate of water. The system of spray nozzles used should be capable of a flow rate of at least 30 L/min (8 gpm) at 275 kPa (40 psi) to soak the cow to the skin. It has been observed that it is best to use 2 or more nozzles approximately 60 cm (24 in) apart to completely cover animal. In an effort to conserve even more water the exit lane soakers can be controlled with a wand or eye beam sensor that controls a solenoid valve so that water is only applied when animals are under the sprinkler heads.

It is also recommended that the return lane sprinklers be located away from the parlor itself to decrease any effects of cows lingering in the return lanes under the soakers and thus affecting the overall cow flow from parlor to housing. In an effort to also minimize the "lingering" an eye beam, or similar, control can be used to control the system. A maximum on time of one minute can be set before the beam would need to broken by the next cow in order the turn the sprinklers on again.

Figure 6.8. Cows are soaked to the skin as they leave the parlor and return to the housing area.

6.2.3: Holding Area Sprinklers

It has been shown that a cow's body temperature can increase 1.7 °C (3 °F) within 20 minutes when in a holding area without cooling, (Harner III et al., 2000). One large cause of this is the fact animals are being held in close quarters with herd mates in the holding area. The use of a sprinkler system in the holding area can help the cow maintain her body temperature throughout the milking routine and return to the housing area.

The goal of the holding area sprinkler system is to wet the cow to the skin and then allow time for her to dry off before wetting again. To soak the animal the sprinkler system needs to apply 1.3 mm (0.05 inches) of water depth to the top of the cows in the holding area in a 1 to 2 minute time period and then allow the cows to dry for 5 to 8 minutes before soaking again. The required volume of water can also be stated as 1.2 L/m^2 (0.03 gal/ft^2). Therefore if a sprinkler is to cover a 6 m (20 ft) diameter area or 29 m^2 (314 ft^2) in 2 minutes it needs a flow rate of 17.8 L/min (4.7 gpm).

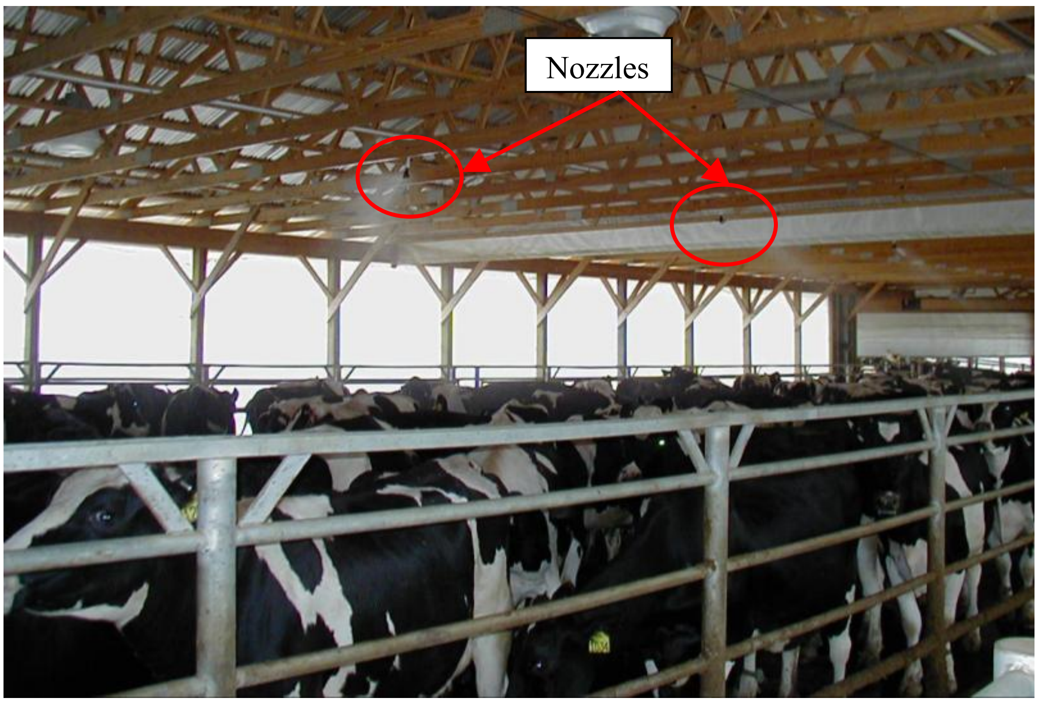

Figure 6.9. Holding area sprinkler system is use.

The spacing and layout of the sprinkler heads will depend on the size of the holding area. Sprinklers should be arranged to ensure coverage of the entire holding area, however caution needs to be used if handling facilities or treatment areas are located along the side of the holding area so that bedding or equipment is not soaked during the operation of the sprinkling system. To help maintain milk quality the holding area sprinkler system must be controlled to avoid wetting the udder. On time of the sprinklers needs to be shortened if the cows entering the parlor have wet udders.

6.3: Indirect Evaporative Cooling to Reduce Interior Air Temperature

6.3.1: Evaporative Cooling Pads

The specific design of an evaporative cooling pad system is dependent on the air exchange capacity of the dairy shelter and the exact pad material chosen. Therefore a qualified designer and installer should be used along with manufacturer's recommendations and specifications to design the system. Below are several general factors that can be used to start the design process.

Figure 6.10. Evaporative cooing pad installed on a tunnel ventilated tiestall shelter.

In general the goal is to achieve 70% to 80% cooling efficiency with a pressure drop across the pad of about 12 Pa (0.05 in H_20) or less. To do this the pad area required can be estimated for a 100 mm (4 inch) thick pad by providing 0.37 m^2 per 28.5 m^3/min (4.0 ft^2/1000 cfm) of fan capacity or for a 150 mm (6 inch) thick pad by providing 0.28 m^2 per 28.5 m^3/min (2.9 ft^2/1000 cfm) of fan capacity. Total fan capacity of the shelter is derived by adding together the fan capacity of each fan to be used as rated at 12 Pa (0.05 in water).

The life of the pad can be extended with regular maintenance. Suggested maintenance would include flushing pads with plenty of water, utilizing algae control techniques, bleeding off return water, flushing the sump, periodically cleaning the pads as per manufacture specifications, and not using chemicals that soften the pads (Strobel et al., 1999).

6.3.2: Foggers/Misters

The goal of a fogging system is to create a very fine, approximately 20 micron, water particle that can be easily evaporated into the air stream as it travels through the dairy shelter. In order to do this most systems operate at 6,900 kPa to 10,300 kPa (1000psi to 1500 psi) requiring one or more pumps in the 1.5 to 6 kW (2 to 8 HP) range. The water is emitted by nozzles located directly in the housing area. The goal is to evaporate as much water as possible as fast as possible. Therefore the nozzles should be located as close to the inlet area as possible. Exact design is dependent on the specifics of the dairy shelter and a designer should be consulted to assist in the design for a given barn.

Care must be taken to not over saturate the air with fog. During periods when the inlet air is at a high relative humidity level the water will be unable to completely evaporate and will settle out of the air onto cows and/or other barn surfaces. If this fog is allowed to settle onto and rest on top of the cows' hair coat it can in fact create an insulation layer on the cow and increase heat buildup in the animal. Fog that settles on the stall bed will increase the moisture of the bedding, and may lead to increased mastitis and somatic cell count issues. Therefore monitoring and/or controls should be in place to shut off part or all of the system during these times when the inlet air is at high humidity.

Maintenance of the system is very important. These nozzles must be kept clean in order to maintain the fine water particles. Water quality is also important and requires excellent filtration to remove minerals and/or particles that could possibly clog the nozzles.

Figure 6.11. High pressure fogging system.

Figure 6.12. Fog in barn created by system.

6.4: Conclusion

A comprehensive heat abatement system consists of increased air exchange, increased air velocity, and evaporative cooling. The exact components used to develop the system for a specific facility will depend on that facility's design, construction, and management.

Chapter 7:

Conclusion

The average annual milk production per cow has increased by 424% since the 1940's. While this increase can be accredited to many factors such as breeding, nutrition, modern management and husbandry, one outcome of this increased production is the increase in metabolic heat production. Therefore today's cows are more sensitive to heat stress than in the past, and today's highest producing herds are at highest risk for production losses caused by heat stress.

Heat abatement of these high producing cows is a complex issue. Heat stress cannot be measured simply by the ambient temperature alone. Factors such as solar load, humidity, air exchange, air velocity, and duration of the heat event must also be considered when addressing heat stress. Heat abatement is a combination of science and art in designing a system to address the needs of a herd on a specific operation with a specific set of local environmental factors, housing, and management.

The "Heat Abatement System Selection Tool" developed in Chapter 5 gives producers, consultants, and designers a logical procedure to the decision process with a set of questions to work through in developing a heat abatement system best suited for an individual dairy operation based on the geographic location, weather conditions, type of shelter, and management to be used on that operation. The Heat Abatement System Selection Tool was developed based on the best research information and field observations available at this time. The tool uses a three step process to arrive at a heat abatement system best suited to the shelter, assuming shade has been provided by the shelter itself. First air exchange of the shelter is maximized, second convective cooling is maximized, and third, if needed, evaporative cooling is added to the system. An example of how the "Heat Abatement System Selection Tool" could be used is illustrated in the Appendix.

In chapter 6 recommendations are made on the design and management of each component that might be used in the total "Heat Abatement System". While more specific design assistance may be needed beyond what is in this thesis the basic concepts of the design and management are addressed here.

Chapter 8:

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Appendix A:

Example of Heat Abatement System Selection Tool

A dairy operation in Central Pennsylvania is expanding by constructing a 4 row, head-to-head, 200 stall (4 groups of 50 stalls) drive through freestall shelter. Each group of 50 stalls has 45.1 m (148 ft) of feed line. The shelter's outside dimensions are 4.3 m high x 31.7 m wide x 98.8 m long (14 ft x 104 ft x 324 ft). Orientation of the building ridge will be East-West and prevailing summer winds at the location are from the South-West. The shelter is to be located in what is now an open ag field with no obstructions for at least 60 m (200 ft) on the windward side. The Heat Abatement System Selection Tool, illustrated in figures 5.1 and 5.2 was used to help design a heat abatement system for this shelter.

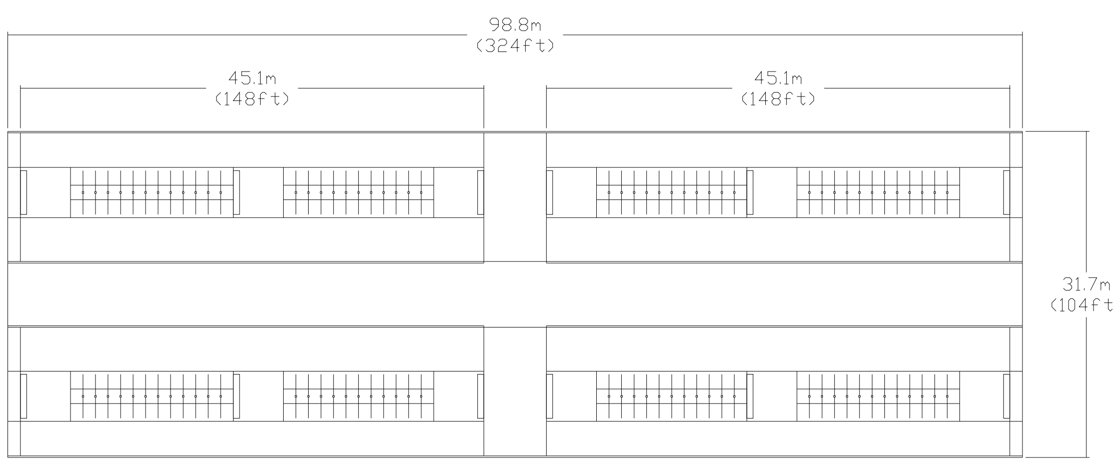


Figure A.1: 200 stall 4 row freestall shelter.

Four groups of 50 stalls each with 45.1 m (148 ft) of feed line per group.

Step 1: Quality of Air Exchange

A natural ventilation factor (NVF) was calculated for the shelter (see Section 5.1). To calculate the wall opening per cow (A_c) it was assumed that 65% of the sidewall area would be open. Therefore A_c = 4.3 m x 98.8 m x 0.65 ÷ 200 = 1.38 m^2/cow (14.8 ft^2/cow), which yields a risk factor of 1. The shelter has a diagonal orientation to prevailing summer winds, which yields a risk factor of 2. The shelter is located in an open ag field giving a risk factor of 1. Therefore the total NVF for the shelter is 4, which indicates potential for good quality natural ventilation.

Step 2: Is Additional Convective Cooling Needed?

To evaluate the need for additional cooling a "Cow Heat Balance" (CHB) model, see Section 2.4, was run using weather data from Selinsgrove, PA for a 31 day period from July 15, 2007 at 9:00 AM to August 15, 2007 at 8:00 AM. Cow Heat Balance was calculated for the 24 hour period beginning at 9:00 AM to 8:00 AM of the next day. The CHB model revealed that with no additional cooling provided to the shelter there was a total of 22 CHB periods (71%) that were greater than zero, therefore additional cooling is needed.

Step 3: Tunnel Ventilation or Circulation Fans

With a Natural Ventilation Factor (NVF) of 4 for the shelter it can be assumed that no difference would exist in heat abatement caused by air exchange between tunnel ventilation and natural ventilation with supplemental axial circulation fans. Therefore a capital and operational cost analysis was done between the two systems (see Section 5.2.1). The basic design and cost assumptions used are as follows:

- Tunnel ventilated shelters designed for air speed of 2.5 m/s (500 fpm).
    - Cross Section = Eave Height x Shelter Width = 31.7m x 4.3m = 136.3m^2
    - Shelter Ventilation Capacity = Cross Section x Air Speed = 136.3m^2 x 2.5 m/s = 20,446 m^3/min
- Tunnel ventilation fans used are 708 m^3/min (25,000 cfm) per fan, consume 1.2 kW·h/hr of operation, and cost $1,200 per fan.
    - Number Fans = Shelter Ventilation Capacity ÷ Fan Capacity = 20,446 m^3/min ÷ 708 m^3/min = 29 fans
    - 30 fans are used for the design to provide an even number on each side of the drive through.
- Supplemental axial circulation fans are spaced 10 times their diameter at 12 m (40 ft) on center over all rows of freestalls and the feed line, consume 1.0 kW·h/hr of operation per fan, and cost $475 per fan A total of 40 fans are needed in the design.

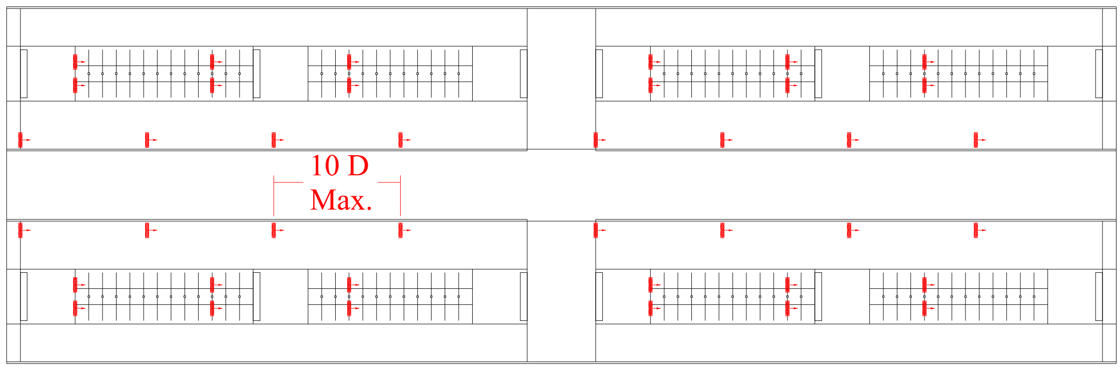


Figure A.2: 200 stall 4 row freestall shelter with 40 1.2 m (4 ft) Axial Circulation fans.

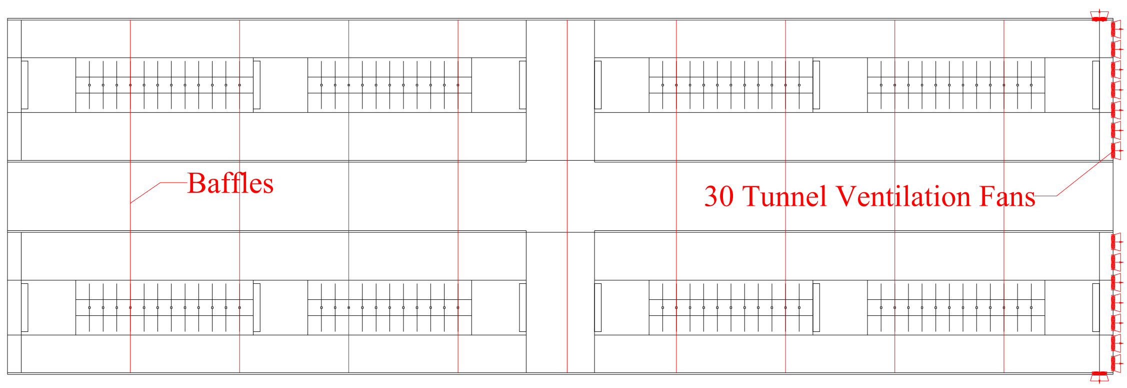


Figure A.3: 200 stall 4 row freestall shelter with 30 Tunnel Ventilation fans.

To estimate operational costs the following management schemes were used along with total number of hours of operation per year as shown in Table A.1.

- Tunnel Ventilation was operated when the temperature was ≥15.5°C (≥60°F).
- Three stages of Natural Ventilation with Supplemental Axial Circulation Fans were used:

- 1/3 of fans in operation at temperature ≥15.5°C and <18°C (≥60°F and <65°F).
- 2/3 of fans in operation at temperature ≥18°F and <20°C (≥65°F and <68°F).
- all fans in operation at temperature ≥20°C (≥68°F).

Table A.1. Average hours per year in a given temperature range. (Selinsgrove, PA)

Temperature Range	Hours per year
Temperature ≥15.5°C (≥60°F)	3100
Temperature ≥15.5°C and <18°C (≥60°F and <65°F)	800
Temperature ≥18°F and <20°C (≥65°F and <68°F)	300
Temperature ≥20°C (≥68°F)	2000

A summary of the capital and operational cost analysis comparison between the two systems can be seen in Table A.2.

Table A.2. Capital and operational cost comparison of example shelter.

	Fan Capital Cost ($)	Hourly Power Usage (kW·h/hr)	Yearly Power Usage (kW·h/yr)
Tunnel Ventilation	30 fans $36,000	36 kW·h/hr	111,600 kW·h/yr
Natural Ventilation with Supplemental Axial Circulation Fans	40 fans $19,000	40 kW·h/hr	100,600 kW·h/yr

Given the significantly higher capital cost and slightly higher operational cost of tunnel ventilation the decision was made to use natural ventilation with supplemental circulation fans in the example shelter.

Step 4: Axial Fans or High Volume Low Speed (HVLS) Fans

Table A.2 was expanded to include HVLS fans using the following assumptions (see Section 5.2.2):

- 7.3 m (24 ft) HVLS fan would be placed over the head-to-head stalls spaced at 2 times their diameter, 14.6 m (48 ft), giving a total of 12 HVLS fans.
- Fans would operate when the temperature was ≥15.5°C (≥60°F) with assumed yearly operational hours of 3100.
- Each fan would cost $4,900 and consume 2.0 kW·h/hr of operation.

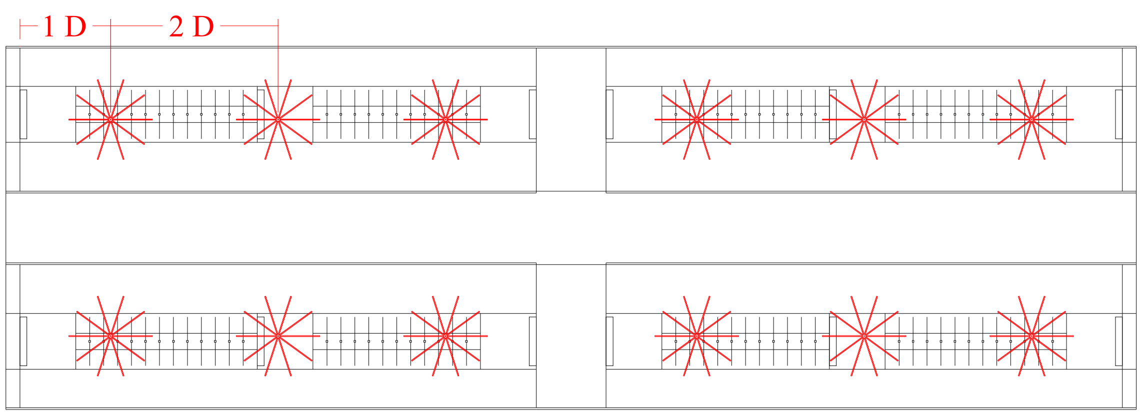


Figure A.4: 200 stall 4 row freestall shelter with 12 7.3 m (24 ft) HVLS fans.

The findings are summarized in the following table.

Table A.3. Capital and operational cost comparison of example shelter.

	Fan Capital Cost ($)	Hourly Power Usage (kW·h/hr)	Yearly Power Usage (kW·h/yr)
Tunnel Ventilation	30 fans $36,000	36 kW·h/hr	111,600 kW·h/yr
Natural Ventilation with Supplemental Axial Circulation Fans	40 fans $19,000	40 kW·h/hr	100,600 kW·h/yr
Natural Ventilation with Supplemental HVLS Fans	12 fans $58,800	24 kW·h/hr	74,400 kW·h/yr

Given the significantly higher capital cost and only slightly lower operational cost of HVLS fans the decision was made to use natural ventilation with supplemental axial circulation fans in the example shelter.

Step 5: Is Evaporative Cooling Needed?

To evaluate the need for additional evaporative cooling (see Section 5.3) the "Cow Heat Balance" (CHB) model was re-run using the same Selinsgrove, PA weather data as before accounting for air exchange and air speed only. The CHB model revealed that with no additional evaporative cooling provided to the shelter there was a total of 16 CHB periods (52%) that were greater than zero, therefore additional evaporative cooling is needed.

Step 6: Direct or In-direct Evaporative Cooling

Since in steps 3 and 4 the decision was made to use natural ventilation with supplemental axial circulation fans, evaporative cooling is limited to a direct evaporative cooling system.

Step 7: Continuous or Periodic Evaporative Cooling

In order to evaluate the option of continuous vs. periodic cooling (see section 5.3.2) the Cow Heat Balance (CHB) model was used again with the following assumptions:

- Continuous evaporative cooling would be used if temp ≥ 21°C (70°F)
- Periodic cooling would be used in holding area and exit lane during milking which is 6:00 AM to 10:00 AM and 6:00 PM to 10:00 PM. A Heat Abatement from Direct Cooling (HAP_{dc}) factor of 2 was assigned for these milking times if the temperature was ≥ 20°C (68°F).

Periodic evaporative cooling only lowered the number of positive CHB periods of 16, found in step 5 by 1 (6% reduction) while the continuous evaporative cooling lowered the positive CHB periods by 10 (62% reduction). Therefore the decision was made to use continuous evaporative cooling.

Summary

The Heat Abatement System Selection Tool was used to develop a heat abatement system for a 4 row 200 stall freestall shelter in Central PA. Using the selection tool it was decided to use natural ventilation with 40 axial supplemental circulation fans placed over the stalls and the feed line along with direct evaporative cooling at the feed line. The following system control criteria will be used with the system:

- Three stages for the axial circulation fans will be used:
    - 1/3 of fans (i.e. 16 fans) in operation at temperature ≥15.5°C and <18°C (≥60°F and <65°F).

- 2/3 of fans (i.e. 26 fans) in operation at temperature ≥18°F and <20°C (≥65°F and <68°F).
- all fans (i.e. 40 fnas) in operation at temperature ≥20°C (≥68°F).

- Three stages for the direct evaporative cooling system will be used:
  - 4 cycle per hour (1 every 15 minutes) for temperature ≥21°C and <27°C (≥70°F and <80°F).
  - 6 cycle per hour (1 every 10 minutes) for temperature ≥27°F and <32°C (≥80°F and <90°F).
  - 12 cycle per hour (1 every 5 minutes) for temperature ≥32°C (≥90°F).

To estimate the water usage of the continuous evaporative cooling system over the 31 day period used in the Cow Heat Balance model the weather data was used with the above system control. Following is a summary table.

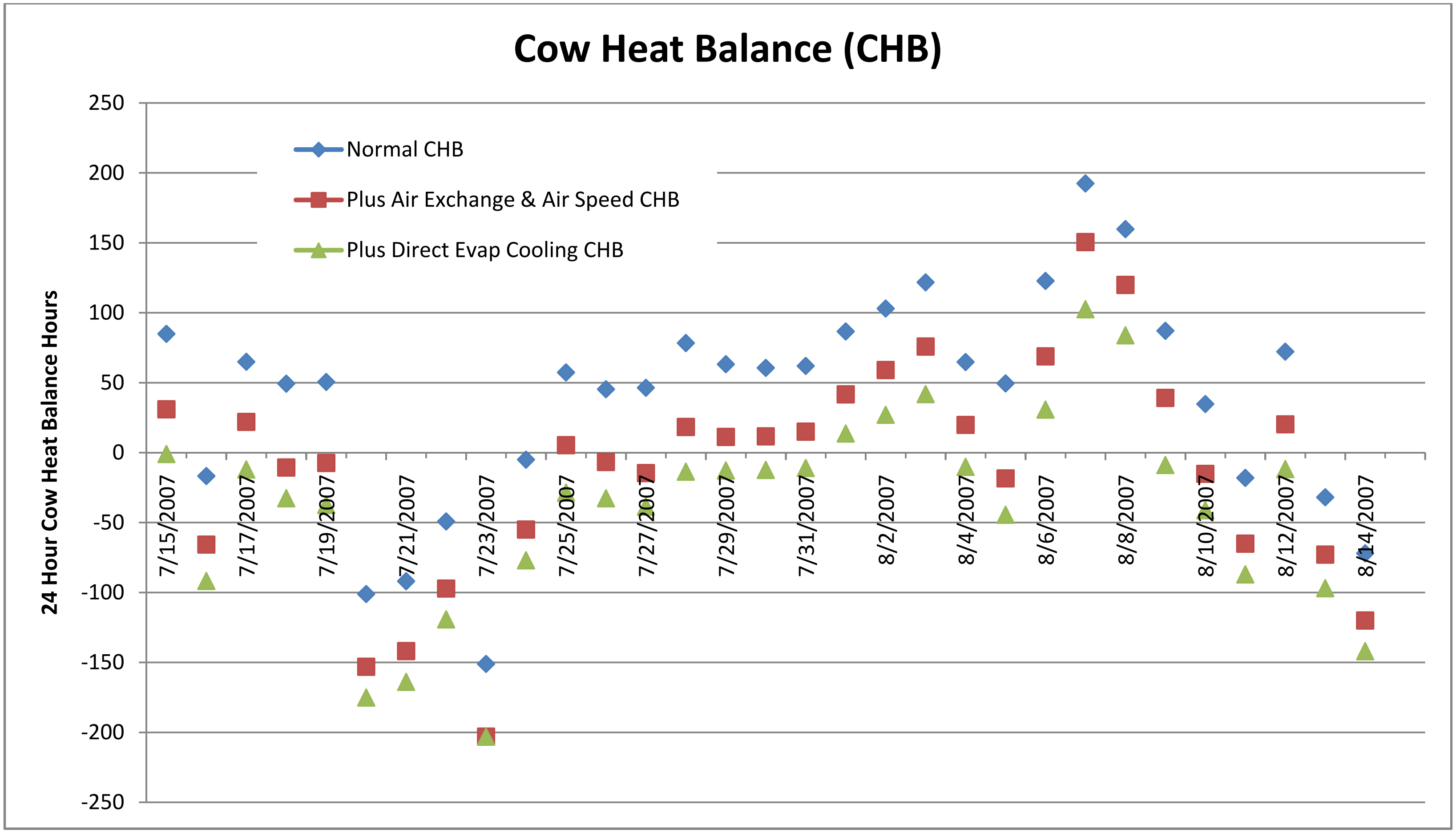
Table A.4. Water usage of continuous direct evaporative cooling system during CHB model period.

	Hours of Operation	Water Usage
4 cycles per hour	207	278,227 liters (73,500 gallons)
6 cycles per hour	199	401,254 liters (106,000 gallons)
12 cycles per hour	90	363,021 liters (95,900 gallons)
Total Water Usage During 31 Day Period		1,042,502 liters (275,400 gallons)

If 50% of the water applied by the direct evaporative cooling system is assumed to runoff in the manure handling system this would increase the manure volume by 521,251 liters (137,700 gallons) during the 31 day period. If manure hauling is assumed to cost \$0.0026 per liter (\$0.01 per gallon) the additional cost to handle the added water would be $1377 for the 31 day period. To estimate the payback of this system if milk is valued at $0.40 per kg ($0.18/lbs), the evaporative cooling system would need to save a total of 3430 kg (7650 lbs) of milk or 0.54 kg/cow/day (1.2 lbs/cow/day) during the 31 day period to break even. Experience would show that level of milk savings is easily achievable.

To graphically display the effects of the heat abatement system on the Cow Heat Balance model of the example shelter for the 31 day period used in the model the following figure was developed. With no heat abatement the Cow Heat Balance (CHB) is greater than zero for 22 of the 31 days. Using natural ventilation with axial circulation fans the CHB remains above zero for 16 of the 31 days. Adding direct evaporative cooling with feed line sprinklers lowers the number of days with a CHB greater than zero to 6 of the 31 days.

Figure A.5. Effects of the heat abatement system on the Cow Heat Balance model of the example shelter.



Appendix B:

Cow Heat Balance From Example

Following is the hourly weather data used to develop the Cow Heat Balance for the example in Appendix A. The data shown is the hourly observations for Selinsgrove, PA for the period of July 15, 2007 at 9:00 AM through August 15, 2007 at 8:00 AM. The data was obtained from the Pennsylvania State Climatologist website at: http://climate.met.psu.edu/data/mesonet/datainv.php.

Five hours of data were missing and four hours of data contained errors (total of 9 bad hours). Surrounding data was extrapolated to fill in to missing data points for a total of 31 days of data

Hourly Observations for *SELINSGROVE, PA* for the period of *7/15/2007* at 9:00 AM through *8/15/2007 at 8:00 AM*.
http://climate.met.psu.edu/data/mesonet/datainv.php
5 hours missing and 4 hours with errors (total of 9 bad hours). Surrounding data was extrapolated to fill in to missing data points
31 days (744 hrs)

							Normal CHB		Plus Air Exchange & Air Speed CHB				Plus Direct Evap Cooling CHB		
Date- Corrected	Hour- Corrected	Temperature	Dewpoint Temperature	Relative Humidity	THI (RH)	CHSH	24 hr sum(9-8)	Days CHB>1	AXF (NV)	HAPam (NV)	NV 24 hr sum(9-8)	NV Days CHB>1	HAPdc	24 hr sum(9-8)	Days CHB>1
MM-DD-YYYY	HHHH (EDST)	deg.F	deg.F	%		1222.503	1222.503	22			-336.497	16		-1204.5	6
7/15/2007	900	75.9	62.9	64	72.4	2.3558	84.9908	1	0	2	30.9908	1	2	-1.0092	0
7/15/2007	1000	80	62	54	74.4	4.434		0	0	2		0	2		0
7/15/2007	1100	84	62	47	76.4	6.421		0	0	2		0	2		0
7/15/2007	1200	84.9	62	46	76.9	6.9107		0	0	2		0	2		0
7/15/2007	1300	87	60	40	77.4	7.43		0	-1	2		0	2		0
7/15/2007	1400	86	60	41	76.9	6.914		0	-1	2		0	2		0
7/15/2007	1500	87	59	38	77.1	7.111		0	-1	2		0	2		0
7/15/2007	1600	87	60.9	41	77.6	7.5895		0	-1	2		0	2		0
7/15/2007	1700	86	60	41	76.9	6.914		0	-1	2		0	2		0
7/15/2007	1800	86	59	40	76.8	6.76		0	-1	2		0	2		0
7/15/2007	1900	84	59	42	75.7	5.706		0	0	2		0	2		0
7/15/2007	2000	82.9	59	44	75.2	5.2308		0	0	2		0	2		0
7/15/2007	2100	80	60.9	52	74.2	4.192		0	0	2		0	2		0
7/15/2007	2200	80	60.9	52	74.2	4.192		0	0	2		0	2		0
7/15/2007	2300	78	60	53	72.8	2.83		0	0	2		0	2		0
7/16/2007	0	73	60	63	69.9	0		0	0	2		0	2		0
7/16/2007	100	68	60	75	66.6	0		0	2	2		0	0		0
7/16/2007	200	68	60.9	78	66.8	0		0	2	2		0	0		0
7/16/2007	300	69	55.9	62	66.7	0		0	2	2		0	0		0
7/16/2007	400	69	55.9	62	66.7	0		0	2	2		0	0		0
7/16/2007	500	68	55	63	66.0	0		0	2	2		0	0		0
7/16/2007	600	66.9	55	65	65.2	0		0	2	0		0	0		0
7/16/2007	700	66.9	57	70	65.4	0		0	2	0		0	0		0
7/16/2007	800	69.9	55.9	61	67.3	0		0	2	2		0	0		0
7/16/2007	900	71.9	55	55	68.5	0	-16.71	0	0	2	-65.71	0	2	-91.71	0
7/16/2007	1000	75.9	55.9	49	70.9	0.87905		0	0	2		0	2		0
7/16/2007	1100	77	55.9	48	71.6	1.566		0	0	2		0	2		0
7/16/2007	1200	80	53.9	40	72.7	2.74		0	0	2		0	2		0
7/16/2007	1300	82	55	39	73.9	3.948		0	0	2		0	2		0
7/16/2007	1400	82	53	36	73.6	3.552		0	0	2		0	2		0
7/16/2007	1500	82.9	55	38	74.4	4.4091		0	0	2		0	2		0
7/16/2007	1600	84.9	55	36	75.4	5.4312		0	0	2		0	2		0
7/16/2007	1700	84.9	55	36	75.4	5.4312		0	0	2		0	2		0
7/16/2007	1800	86	51.9	31	75.4	5.374		0	-1	2		0	2		0
7/16/2007	1900	84.9	51	31	74.7	4.69145		0	0	2		0	2		0
7/16/2007	2000	75.9	57.9	53	71.3	1.27285		0	0	2		0	2		0
7/16/2007	2100	71	55	56	67.9	0		0	0	2		0	2		0

7/16/2007	2200	62.9	57	80	62.4	-2.639		0	2	0		0	0		0
7/16/2007	2300	60.9	55.9	83	60.6	-4.37115		0	2	0		0	0		0
7/17/2007	0	59	55	86	58.9	-6.077		0	2	0		0	0		0
7/17/2007	100	60	55	83	59.8	-5.187		0	2	0		0	0		0
7/17/2007	200	60	55.9	86	59.8	-5.154		0	2	0		0	0		0
7/17/2007	300	57.9	55	90	57.9	-7.0945		0	2	0		0	0		0
7/17/2007	400	59	55	86	58.9	-6.077		0	2	0		0	0		0
7/17/2007	500	57.9	55	90	57.9	-7.0945		0	2	0		0	0		0
7/17/2007	600	57	53.9	89	57.1	-7.9395		0	2	0		0	0		0
7/17/2007	700	60.9	55.9	83	60.6	-4.37115		0	2	0		0	0		0
7/17/2007	800	69	55.9	62	66.7	0		0	2	2		0	0		0
7/17/2007	900	73.9	57	55	70.0	0	64.99565	1	0	2	21.99565	1	2	-12.0044	0
7/17/2007	1000	77	57	50	71.8	1.775		0	0	2		0	2		0
7/17/2007	1100	80	55.9	43	73.1	3.103		0	0	2		0	2		0
7/17/2007	1200	82.9	51	33	73.7	3.72435		0	0	2		0	2		0
7/17/2007	1300	84.9	55	36	75.4	5.4312		0	0	2		0	2		0
7/17/2007	1400	86	55	34	75.8	5.836		0	-1	2		0	2		0
7/17/2007	1500	86	53.9	33	75.7	5.682		0	-1	2		0	2		0
7/17/2007	1600	87.9	55	32	76.7	6.7174		0	-1	2		0	2		0
7/17/2007	1700	87	55	33	76.3	6.3135		0	-1	2		0	2		0
7/17/2007	1800	86	53.9	33	75.7	5.682		0	-1	2		0	2		0
7/17/2007	1900	84.9	53.9	34	75.1	5.1353		0	0	2		0	2		0
7/17/2007	2000	82	55	39	73.9	3.948		0	0	2		0	2		0
7/17/2007	2100	80.9	55	40	73.3	3.343		0	0	2		0	2		0
7/17/2007	2200	80.9	53.9	39	73.2	3.21705		0	0	2		0	2		0
7/17/2007	2300	78.9	55	43	72.3	2.34785		0	0	2		0	2		0
7/18/2007	0	80	53.9	40	72.7	2.74		0	0	2		0	2		0
7/18/2007	100	71.9	62	71	69.7	0		0	0	2		0	2		0
7/18/2007	200	66.9	62.9	87	66.3	0		0	2	0		0	0		0
7/18/2007	300	66.9	64	90	66.4	0		0	2	0		0	0		0
7/18/2007	400	66.9	64	90	66.4	0		0	2	0		0	0		0
7/18/2007	500	66	64	93	65.7	0		0	2	0		0	0		0
7/18/2007	600	66	64	93	65.7	0		0	2	0		0	0		0
7/18/2007	700	66.9	64	90	66.4	0		0	2	0		0	0		0
7/18/2007	800	66.9	64	90	66.4	0		0	2	0		0	0		0
7/18/2007	900	69	64.9	86	68.2	0	49.384	1	2	2	-10.616	0	0	-32.616	0
7/18/2007	1000	69	64.9	86	68.2	0		0	2	2		0	0		0
7/18/2007	1100	69.9	66	87	69.0	0		0	2	2		0	0		0
7/18/2007	1200	73.9	66	76	71.8	1.8012		0	0	2		0	2		0
7/18/2007	1300	78	68	71	74.8	4.81		0	0	2		0	2		0
7/18/2007	1400	82	66.9	60	76.7	6.72		0	0	2		0	2		0
7/18/2007	1500	80.9	66	60	75.9	5.862		0	0	2		0	2		0
7/18/2007	1600	82	66	58	76.5	6.456		0	0	2		0	2		0
7/18/2007	1700	82	64.9	56	76.2	6.192		0	0	2		0	2		0
7/18/2007	1800	78.9	69.9	73	75.8	5.79635		0	0	2		0	2		0
7/18/2007	1900	82	68	62	77.0	6.984		0	0	2		0	2		0

7/18/2007	2000	75.9	66	71	73.0	3.04495		0	0	2		0	2		0
7/18/2007	2100	73	66.9	81	71.4	1.4325		0	0	2		0	2		0
7/18/2007	2200	71	68	90	70.3	0.285		0	0	2		0	2		0
7/18/2007	2300	69	66.9	92	68.5	0		0	2	2		0	0		0
7/19/2007	0	66.9	64.9	93	66.6	0		0	2	0		0	0		0
7/19/2007	100	66.9	64.9	93	66.6	0		0	2	0		0	0		0
7/19/2007	200	66	64	93	65.7	0		0	2	0		0	0		0
7/19/2007	300	66	64	93	65.7	0		0	2	0		0	0		0
7/19/2007	400	66	64	93	65.7	0		0	2	0		0	0		0
7/19/2007	500	66	64	93	65.7	0		0	2	0		0	0		0
7/19/2007	600	66.9	64	90	66.4	0		0	2	0		0	0		0
7/19/2007	700	68	64.9	89	67.4	0		0	2	2		0	0		0
7/19/2007	800	69.9	66	87	69.0	0		0	2	2		0	0		0
7/19/2007	900	71	66	84	69.9	0	50.6015	1	0	2	-7.3985	0	2	-37.3985	0
7/19/2007	1000	71.9	66.9	84	70.7	0.6768		0	0	2		0	2		0
7/19/2007	1100	73.9	66.9	78	72.0	1.9761		0	0	2		0	2		0
7/19/2007	1200	77	68	73	74.2	4.1785		0	0	2		0	2		0
7/19/2007	1300	77	68	73	74.2	4.1785		0	0	2		0	2		0
7/19/2007	1400	77	68	73	74.2	4.1785		0	0	2		0	2		0
7/19/2007	1500	80	69	69	76.2	6.249		0	0	2		0	2		0
7/19/2007	1600	82.9	66.9	58	77.1	7.1481		0	0	2		0	2		0
7/19/2007	1700	82	66.9	60	76.7	6.72		0	0	2		0	2		0
7/19/2007	1800	80	66.9	64	75.6	5.644		0	0	2		0	2		0
7/19/2007	1900	80.9	66	60	75.9	5.862		0	0	2		0	2		0
7/19/2007	2000	77	69	76	74.5	4.492		0	0	2		0	2		0
7/19/2007	2100	75	66.9	75	72.7	2.6625		0	0	2		0	2		0
7/19/2007	2200	71.9	69	90	71.1	1.1355		0	0	2		0	2		0
7/19/2007	2300	71	66.9	86	70.0	0		0	0	2		0	2		0
7/20/2007	0	69.9	66.9	90	69.2	0		0	2	2		0	0		0
7/20/2007	100	69.9	66.9	90	69.2	0		0	2	2		0	0		0
7/20/2007	200	69.9	66	87	69.0	0		0	2	2		0	0		0
7/20/2007	300	69.9	64.9	84	68.9	0		0	2	2		0	0		0
7/20/2007	400	68	62	81	67.0	0		0	2	2		0	0		0
7/20/2007	500	66.9	60.9	81	66.0	0		0	2	0		0	0		0
7/20/2007	600	64.9	57	75	64.0	-1.04875		0	2	0		0	0		0
7/20/2007	700	64	53.9	69	63.0	-2.023		0	2	0		0	0		0
7/20/2007	800	64.9	53	65	63.6	-1.42825		0	2	0		0	0		0
7/20/2007	900	68	51.9	56	65.6	0	-101.057	0	2	2	-153.057	0	0	-175.057	0
7/20/2007	1000	71	53	52	67.6	0		0	0	2		0	2		0
7/20/2007	1100	71.9	51.9	49	68.0	0		0	0	2		0	2		0
7/20/2007	1200	75.2	52	47	70.2	0.1862		0	0	2		0	2		0
7/20/2007	1300	76.7	52.5	45	71.0	1.04325		0	0	2		0	2		0
7/20/2007	1400	77.5	53	43	71.4	1.38675		0	0	2		0	2		0
7/20/2007	1500	78	53	41	71.5	1.51		0	0	2		0	2		0
7/20/2007	1600	77	53	43	71.0	1.0435		0	0	2		0	2		0
7/20/2007	1700	78	53.9	43	71.7	1.73		0	0	2		0	2		0

7/20/2007	1800	78	51.9	40	71.4	1.4		0	0	2		0	2		0
7/20/2007	1900	75.9	51.9	43	70.3	0.28835		0	0	2		0	2		0
7/20/2007	2000	73	50	44	68.4	0		0	0	2		0	2		0
7/20/2007	2100	69	50	50	66.0	0		0	2	2		0	0		0
7/20/2007	2200	66	51	58	64.2	-0.848		0	2	0		0	0		0
7/20/2007	2300	60.9	51	69	60.4	-4.59445		0	2	0		0	0		0
7/21/2007	0	57	53	86	57.1	-7.923		0	2	0		0	0		0
7/21/2007	100	55	53	93	55.1	-9.8845		0	2	0		0	0		0
7/21/2007	200	53	51.9	96	53.1	-11.89		0	2	0		0	0		0
7/21/2007	300	51.9	51	96	52.0	-12.9658		0	2	0		0	0		0
7/21/2007	400	51.9	50	92	52.2	-12.8316		0	2	0		0	0		0
7/21/2007	500	50	48.9	96	50.2	-14.824		0	2	0		0	0		0
7/21/2007	600	48.9	48	96	49.1	-15.8998		0	2	0		0	0		0
7/21/2007	700	53	51.9	96	53.1	-11.89		0	2	0		0	0		0
7/21/2007	800	59	53.9	83	58.9	-6.0935		0	2	0		0	0		0
7/21/2007	900	66.9	55	65	65.2	0	-91.8874	0	2	0	-141.887	0	0	-163.887	0
7/21/2007	1000	71.9	53.9	53	68.3	0		0	0	2		0	2		0
7/21/2007	1100	75.9	51.9	43	70.3	0.28835		0	0	2		0	2		0
7/21/2007	1200	77	51	40	70.7	0.73		0	0	2		0	2		0
7/21/2007	1300	78	48.9	35	70.9	0.85		0	0	2		0	2		0
7/21/2007	1400	80	48.9	33	71.9	1.893		0	0	2		0	2		0
7/21/2007	1500	80.9	48.9	32	72.3	2.3354		0	0	2		0	2		0
7/21/2007	1600	82	48	30	72.8	2.76		0	0	2		0	2		0
7/21/2007	1700	80.9	44.9	28	71.8	1.8316		0	0	2		0	2		0
7/21/2007	1800	77	46	33	70.0	0		0	0	2		0	2		0
7/21/2007	1900	78.9	46.9	32	71.1	1.0834		0	0	2		0	2		0
7/21/2007	2000	75	46.9	36	69.0	0		0	0	2		0	2		0
7/21/2007	2100	64.9	51.9	62	63.5	-1.5421		0	2	0		0	0		0
7/21/2007	2200	68	48.9	50	65.3	0		0	2	2		0	0		0
7/21/2007	2300	60	51.9	74	59.7	-5.286		0	2	0		0	0		0
7/22/2007	0	57	53	86	57.1	-7.923		0	2	0		0	0		0
7/22/2007	100	53.9	51.9	92	54.1	-10.9196		0	2	0		0	0		0
7/22/2007	200	55	51.9	89	55.2	-9.8185		0	2	0		0	0		0
7/22/2007	300	53	51	92	53.2	-11.78		0	2	0		0	0		0
7/22/2007	400	51	48.9	92	51.3	-13.692		0	2	0		0	0		0
7/22/2007	500	50	48	92	50.4	-14.648		0	2	0		0	0		0
7/22/2007	600	51	48.9	92	51.3	-13.692		0	2	0		0	0		0
7/22/2007	700	53.9	51	89	54.1	-10.852		0	2	0		0	0		0
7/22/2007	800	62	55	77	61.5	-3.506		0	2	0		0	0		0
7/22/2007	900	66.9	53.9	63	65.1	0	-49.1618	0	2	0	-97.1618	0	0	-119.162	0
7/22/2007	1000	71	53	52	67.6	0		0	0	2		0	2		0
7/22/2007	1100	75	51.9	44	69.8	0		0	0	2		0	2		0
7/22/2007	1200	77	51.9	41	70.8	0.8345		0	0	2		0	2		0
7/22/2007	1300	80	44.9	28	71.3	1.288		0	0	2		0	2		0
7/22/2007	1400	82	48	30	72.8	2.76		0	0	2		0	2		0
7/22/2007	1500	82	48.9	31	72.9	2.892		0	0	2		0	2		0

7/22/2007	1600	82	48.9	31	72.9	2.892		0	0	2		0	2		0
7/22/2007	1700	82	48.9	31	72.9	2.892		0	0	2		0	2		0
7/22/2007	1800	80.9	50	34	72.6	2.5873		0	0	2		0	2		0
7/22/2007	1900	78	48.9	35	70.9	0.85		0	0	2		0	2		0
7/22/2007	2000	73.9	53	48	69.4	0		0	0	2		0	2		0
7/22/2007	2100	66.9	57	70	65.4	0		0	2	0		0	0		0
7/22/2007	2200	62.9	55.9	77	62.3	-2.71985		0	2	0		0	0		0
7/22/2007	2300	60.9	55.9	83	60.6	-4.37115		0	2	0		0	0		0
7/23/2007	0	59	55	86	58.9	-6.077		0	2	0		0	0		0
7/23/2007	100	57	55	93	57.0	-7.9615		0	2	0		0	0		0
7/23/2007	200	57.9	55	90	57.9	-7.0945		0	2	0		0	0		0
7/23/2007	300	57	55	93	57.0	-7.9615		0	2	0		0	0		0
7/23/2007	400	57.9	53.9	86	57.9	-7.0923		0	2	0		0	0		0
7/23/2007	500	57.9	55	90	57.9	-7.0945		0	2	0		0	0		0
7/23/2007	600	57.9	53.9	86	57.9	-7.0923		0	2	0		0	0		0
7/23/2007	700	60	55	83	59.8	-5.187		0	2	0		0	0		0
7/23/2007	800	62	55	77	61.5	-3.506		0	2	0		0	0		0
7/23/2007	900	62.9	55	75	62.2	-2.77375	-151.027	0	2	0	-203.027	0	0	-203.027	0
7/23/2007	1000	64.9	55	70	63.8	-1.2385		0	2	0		0	0		0
7/23/2007	1100	64	57.9	80	63.3	-1.66		0	2	0		0	0		0
7/23/2007	1200	66.5	58.5	75	65.3	0		0	2	0		0	0		0
7/23/2007	1300	69	59	70	67.2	0		0	2	2		0	0		0
7/23/2007	1400	68	57.9	70	66.4	0		0	2	2		0	0		0
7/23/2007	1500	62.9	57.9	83	62.4	-2.55815		0	2	0		0	0		0
7/23/2007	1600	64	57.9	80	63.3	-1.66		0	2	0		0	0		0
7/23/2007	1700	64.9	57.9	77	64.0	-0.97285		0	2	0		0	0		0
7/23/2007	1800	66	57	72	64.8	-0.232		0	2	0		0	0		0
7/23/2007	1900	66	55	67	64.5	-0.452		0	2	0		0	0		0
7/23/2007	2000	64.9	55.9	72	63.8	-1.1626		0	2	0		0	0		0
7/23/2007	2100	64	55	72	63.1	-1.924		0	2	0		0	0		0
7/23/2007	2200	60	55.9	86	59.8	-5.154		0	2	0		0	0		0
7/23/2007	2300	55.9	55	96	55.9	-9.0538		0	2	0		0	0		0
7/24/2007	0	53	53	100	53.0	-12		0	2	0		0	0		0
7/24/2007	100	53	51.9	96	53.1	-11.89		0	2	0		0	0		0
7/24/2007	200	51	50	96	51.2	-13.846		0	2	0		0	0		0
7/24/2007	300	51	50	96	51.2	-13.846		0	2	0		0	0		0
7/24/2007	400	48.9	48	96	49.1	-15.8998		0	2	0		0	0		0
7/24/2007	500	48	46.9	96	48.2	-16.78		0	2	0		0	0		0
7/24/2007	600	50	48.9	96	50.2	-14.824		0	2	0		0	0		0
7/24/2007	700	51.9	51.9	100	51.9	-13.1		0	2	0		0	0		0
7/24/2007	800	55	55	100	55.0	-10		0	2	0		0	0		0
7/24/2007	900	57.9	57	96	57.9	-7.0978	-4.9489	0	2	0	-54.9489	0	0	-76.9489	0
7/24/2007	1000	66.9	57	70	65.4	0		0	2	0		0	0		0
7/24/2007	1100	71	55.9	58	68.0	0		0	0	2		0	2		0
7/24/2007	1200	75	55.9	51	70.4	0.4185		0	0	2		0	2		0
7/24/2007	1300	78.9	57	46	72.7	2.6927		0	0	2		0	2		0

7/24/2007	1400	80.9	55.9	42	73.6	3.5949		0	0	2		0	2		0
7/24/2007	1500	82.9	57	41	74.8	4.81995		0	0	2		0	2		0
7/24/2007	1600	84	57.9	41	75.6	5.563		0	0	2		0	2		0
7/24/2007	1700	80	57	45	73.3	3.345		0	0	2		0	2		0
7/24/2007	1800	77	59	53	72.1	2.0885		0	0	2		0	2		0
7/24/2007	1900	75.9	59	55	71.5	1.46975		0	0	2		0	2		0
7/24/2007	2000	71.9	62	71	69.7	0		0	0	2		0	2		0
7/24/2007	2100	71	62.9	75	69.2	0		0	0	2		0	2		0
7/24/2007	2200	69.9	62	75	68.3	0		0	2	2		0	0		0
7/24/2007	2300	66	64.9	96	65.8	0		0	2	0		0	0		0
7/25/2007	0	64	64	100	64.0	-1		0	2	0		0	0		0
7/25/2007	100	62	62	100	62.0	-3		0	2	0		0	0		0
7/25/2007	200	62	60.9	96	61.9	-3.088		0	2	0		0	0		0
7/25/2007	300	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
7/25/2007	400	62	60.9	96	61.9	-3.088		0	2	0		0	0		0
7/25/2007	500	60.9	60	96	60.8	-4.1638		0	2	0		0	0		0
7/25/2007	600	62	60.9	96	61.9	-3.088		0	2	0		0	0		0
7/25/2007	700	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
7/25/2007	800	66	64.9	96	65.8	0		0	2	0		0	0		0
7/25/2007	900	69.9	64.9	84	68.9	0	57.38425	1	2	2	5.38425	1	0	-28.6158	0
7/25/2007	1000	75	64	68	72.0	2.008		0	0	2		0	2		0
7/25/2007	1100	77	64	64	73.2	3.238		0	0	2		0	2		0
7/25/2007	1200	80	62	54	74.4	4.434		0	0	2		0	2		0
7/25/2007	1300	80.9	60	49	74.5	4.47655		0	0	2		0	2		0
7/25/2007	1400	82.9	60	46	75.5	5.5047		0	0	2		0	2		0
7/25/2007	1500	84.9	60	43	76.5	6.46685		0	0	2		0	2		0
7/25/2007	1600	84	60	44.5	76.1	6.0635		0	0	2		0	2		0
7/25/2007	1700	82.9	60	46	75.5	5.5047		0	0	2		0	2		0
7/25/2007	1800	82.9	60.9	47	75.6	5.64165		0	0	2		0	2		0
7/25/2007	1900	82	60.9	48	75.1	5.136		0	0	2		0	2		0
7/25/2007	2000	78.9	62	56	73.8	3.8422		0	0	2		0	2		0
7/25/2007	2100	75	62	64	71.6	1.634		0	0	2		0	2		0
7/25/2007	2200	75.9	62	62	72.2	2.1589		0	0	2		0	2		0
7/25/2007	2300	75.9	62.9	64	72.4	2.3558		0	0	2		0	2		0
7/26/2007	0	73.9	62.9	68	71.1	1.1016		0	0	2		0	2		0
7/26/2007	100	68	64	87	67.3	0		0	2	2		0	0		0
7/26/2007	200	66	62.9	89	65.5	0		0	2	0		0	0		0
7/26/2007	300	71	62.9	75	69.2	0		0	0	2		0	2		0
7/26/2007	400	64.9	62.9	93	64.6	-0.36565		0	2	0		0	0		0
7/26/2007	500	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
7/26/2007	600	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
7/26/2007	700	66.9	64.9	93	66.6	0		0	2	0		0	0		0
7/26/2007	800	71.9	66	81	70.4	0.44745		0	0	2		0	2		0
7/26/2007	900	75	66.9	75	72.7	2.6625	45.37235	1	0	2	-6.62765	0	2	-32.6276	0
7/26/2007	1000	77	66.9	71	74.0	3.9695		0	0	2		0	2		0
7/26/2007	1100	78.9	68	69	75.3	5.33655		0	0	2		0	2		0

7/26/2007	1200	80.9	66.9	62	76.1	6.1139		0	0	2		0	2		0
7/26/2007	1300	82.9	66.9	58	77.1	7.1481		0	0	2		0	2		0
7/26/2007	1400	80.9	66.9	62	76.1	6.1139		0	0	2		0	2		0
7/26/2007	1500	75	69	81	73.2	3.2235		0	0	2		0	2		0
7/26/2007	1600	73.9	68	81	72.2	2.23845		0	0	2		0	2		0
7/26/2007	1700	78	66	66	74.3	4.26		0	0	2		0	2		0
7/26/2007	1800	78.9	62.9	57	74.0	3.95715		0	0	2		0	2		0
7/26/2007	1900	78	64.9	64	74.0	4.04		0	0	2		0	2		0
7/26/2007	2000	73	68	84	71.7	1.68		0	0	2		0	2		0
7/26/2007	2100	69.9	66.9	90	69.2	0		0	2	2		0	0		0
7/26/2007	2200	69	66.9	92	68.5	0		0	2	2		0	0		0
7/26/2007	2300	66.9	64.9	93	66.6	0		0	2	0		0	0		0
7/27/2007	0	66	64.9	96	65.8	0		0	2	0		0	0		0
7/27/2007	100	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
7/27/2007	200	62.9	62.9	100	62.9	-2.1		0	2	0		0	0		0
7/27/2007	300	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
7/27/2007	400	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/27/2007	500	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/27/2007	600	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/27/2007	700	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/27/2007	800	71	66.9	86	70.0	0		0	0	2		0	2		0
7/27/2007	900	75.9	68	76	73.5	3.5372	46.4424	1	0	2	-14.5576	0	2	-38.5576	0
7/27/2007	1000	78	66.9	68	74.5	4.48		0	0	2		0	2		0
7/27/2007	1100	77	66.9	71	74.0	3.9695		0	0	2		0	2		0
7/27/2007	1200	80.9	68	64	76.4	6.3658		0	0	2		0	2		0
7/27/2007	1300	82	66.9	60	76.7	6.72		0	0	2		0	2		0
7/27/2007	1400	86	64.9	49	78.1	8.146		0	-1	2		0	2		0
7/27/2007	1500	84	64	51	77.0	6.993		0	0	2		0	2		0
7/27/2007	1600	71.9	66	81	70.4	0.44745		0	0	2		0	2		0
7/27/2007	1700	73	66.9	81	71.4	1.4325		0	0	2		0	2		0
7/27/2007	1800	73	66.9	81	71.4	1.4325		0	0	2		0	2		0
7/27/2007	1900	73	68	84	71.7	1.68		0	0	2		0	2		0
7/27/2007	2000	73.9	68	81	72.2	2.23845		0	0	2		0	2		0
7/27/2007	2100	69.9	69	96	69.6	0		0	2	2		0	0		0
7/27/2007	2200	69.9	68	93	69.4	0		0	2	2		0	0		0
7/27/2007	2300	69	68	96	68.8	0		0	2	2		0	0		0
7/28/2007	0	68	66.9	96	67.8	0		0	2	2		0	0		0
7/28/2007	100	66.9	66	96	66.7	0		0	2	0		0	0		0
7/28/2007	200	66	64.9	96	65.8	0		0	2	0		0	0		0
7/28/2007	300	64	64	100	64.0	-1		0	2	0		0	0		0
7/28/2007	400	66	66	100	66.0	0		0	2	0		0	0		0
7/28/2007	500	66.9	66	96	66.7	0		0	2	0		0	0		0
7/28/2007	600	68	66.9	96	67.8	0		0	2	2		0	0		0
7/28/2007	700	68	66.9	96	67.8	0		0	2	2		0	0		0
7/28/2007	800	69.9	68	93	69.4	0		0	2	2		0	0		0
7/28/2007	900	71	68	90	70.3	0.285	78.40645	1	0	2	18.40645	1	2	-13.5936	0

7/28/2007	1000	73	68	84	71.7	1.68		0	0	2		0	2		0
7/28/2007	1100	78	69	73	75.0	5.03		0	0	2		0	2		0
7/28/2007	1200	80	69	69	76.2	6.249		0	0	2		0	2		0
7/28/2007	1300	82.9	66.9	58	77.1	7.1481		0	0	2		0	2		0
7/28/2007	1400	84.9	66	53	77.9	7.94635		0	0	2		0	2		0
7/28/2007	1500	86	66	51	78.5	8.454		0	-1	2		0	2		0
7/28/2007	1600	86	64.9	49	78.1	8.146		0	-1	2		0	2		0
7/28/2007	1700	87	64	46	78.4	8.387		0	-1	2		0	2		0
7/28/2007	1800	86	64.9	49	78.1	8.146		0	-1	2		0	2		0
7/28/2007	1900	82	68	62	77.0	6.984		0	0	2		0	2		0
7/28/2007	2000	75	69.9	84	73.5	3.504		0	0	2		0	2		0
7/28/2007	2100	73	71	93	72.4	2.4225		0	0	2		0	2		0
7/28/2007	2200	73	69.9	90	72.2	2.175		0	0	2		0	2		0
7/28/2007	2300	71	69.9	96	70.7	0.714		0	0	2		0	2		0
7/29/2007	0	69.9	69	96	69.6	0		0	2	2		0	0		0
7/29/2007	100	68	66.9	96	67.8	0		0	2	2		0	0		0
7/29/2007	200	69.9	68	93	69.4	0		0	2	2		0	0		0
7/29/2007	300	69	68	96	68.8	0		0	2	2		0	0		0
7/29/2007	400	69	68	96	68.8	0		0	2	2		0	0		0
7/29/2007	500	69	68	96	68.8	0		0	2	2		0	0		0
7/29/2007	600	69	66.9	92	68.5	0		0	2	2		0	0		0
7/29/2007	700	69	68	96	68.8	0		0	2	2		0	0		0
7/29/2007	800	71.9	69	90	71.1	1.1355		0	0	2		0	2		0
7/29/2007	900	75.9	68	76	73.5	3.5372	63.2681	1	0	2	11.2681	1	2	-12.7319	0
7/29/2007	1000	78	68	71	74.8	4.81		0	0	2		0	2		0
7/29/2007	1100	78.9	66.9	66	75.0	4.9917		0	0	2		0	2		0
7/29/2007	1200	80	68	66	75.9	5.886		0	0	2		0	2		0
7/29/2007	1300	82.9	69	63	77.8	7.83285		0	0	2		0	2		0
7/29/2007	1400	82	69	64	77.2	7.248		0	0	2		0	2		0
7/29/2007	1500	84	68	58	78.0	7.994		0	0	2		0	2		0
7/29/2007	1600	84.9	68	56	78.4	8.3902		0	0	2		0	2		0
7/29/2007	1700	82.9	69	63	77.8	7.83285		0	0	2		0	2		0
7/29/2007	1800	75	66.9	75	72.7	2.6625		0	0	2		0	2		0
7/29/2007	1900	73.5	67.5	81	71.9	1.88025		0	0	2		0	2		0
7/29/2007	2000	71.9	68	87	70.9	0.90615		0	0	2		0	2		0
7/29/2007	2100	69	68	96	68.8	0		0	2	2		0	0		0
7/29/2007	2200	68	66.9	96	67.8	0		0	2	2		0	0		0
7/29/2007	2300	66.9	66	96	66.7	0		0	2	0		0	0		0
7/30/2007	0	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/30/2007	100	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/30/2007	200	66	66	100	66.0	0		0	2	0		0	0		0
7/30/2007	300	66.9	66.9	100	66.9	0		0	2	0		0	0		0
7/30/2007	400	66	66	100	66.0	0		0	2	0		0	0		0
7/30/2007	500	64.9	64.9	100	64.9	-0.1		0	2	0		0	0		0
7/30/2007	600	64.9	64.9	100	64.9	-0.1		0	2	0		0	0		0
7/30/2007	700	66	66	100	66.0	0		0	2	0		0	0		0

7/30/2007	800	66.9	66	96	66.7	0		0	2	0		0	0		0
7/30/2007	900	66.9	66.9	100	66.9	0	60.67505	1	2	0	11.67505	1	0	-12.325	0
7/30/2007	1000	69.9	66.9	90	69.2	0		0	2	2		0	0		0
7/30/2007	1100	73.9	68	81	72.2	2.23845		0	0	2		0	2		0
7/30/2007	1200	80	68	66	75.9	5.886		0	0	2		0	2		0
7/30/2007	1300	82.9	64.9	54	76.6	6.6003		0	0	2		0	2		0
7/30/2007	1400	87	62	43	77.9	7.9085		0	-1	2		0	2		0
7/30/2007	1500	87	62	43	77.9	7.9085		0	-1	2		0	2		0
7/30/2007	1600	87	64	46	78.4	8.387		0	-1	2		0	2		0
7/30/2007	1700	87.9	64	45	78.9	8.85525		0	-1	2		0	2		0
7/30/2007	1800	86	66	51	78.5	8.454		0	-1	2		0	2		0
7/30/2007	1900	84	64.9	52	77.1	7.136		0	0	2		0	2		0
7/30/2007	2000	78	68	71	74.8	4.81		0	0	2		0	2		0
7/30/2007	2100	77	66.9	71	74.0	3.9695		0	0	2		0	2		0
7/30/2007	2200	71.9	66.9	84	70.7	0.6768		0	0	2		0	2		0
7/30/2007	2300	69.5	66.9	93	69.1	0		0	2	2		0	0		0
7/31/2007	0	66.9	66.9	100	66.9	0		0	2	0		0	0		0
7/31/2007	100	66	66	100	66.0	0		0	2	0		0	0		0
7/31/2007	200	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
7/31/2007	300	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
7/31/2007	400	64	62	93	63.8	-1.231		0	2	0		0	0		0
7/31/2007	500	62.9	60.9	93	62.7	-2.28865		0	2	0		0	0		0
7/31/2007	600	60.9	60	96	60.8	-4.1638		0	2	0		0	0		0
7/31/2007	700	62	60.9	96	61.9	-3.088		0	2	0		0	0		0
7/31/2007	800	68	62.9	83	67.1	0		0	2	2		0	0		0
7/31/2007	900	71.9	60.9	68	69.5	0	62.0418	1	0	2	15.0418	1	2	-10.9582	0
7/31/2007	1000	77	60	55	72.3	2.2975		0	0	2		0	2		0
7/31/2007	1100	80	57.9	46	73.5	3.466		0	0	2		0	2		0
7/31/2007	1200	82	59	45	74.7	4.74		0	0	2		0	2		0
7/31/2007	1300	84	60	44	76.0	5.992		0	0	2		0	2		0
7/31/2007	1400	84.9	60	43	76.5	6.46685		0	0	2		0	2		0
7/31/2007	1500	87.9	60	39	77.9	7.86855		0	-1	2		0	2		0
7/31/2007	1600	89	60.9	39	78.6	8.5995		0	-1	2		0	2		0
7/31/2007	1700	87.9	59	37	77.5	7.53965		0	-1	2		0	2		0
7/31/2007	1800	87.9	62	42	78.4	8.3619		0	-1	2		0	2		0
7/31/2007	1900	87.9	60.9	40	78.0	8.033		0	-1	2		0	2		0
7/31/2007	2000	77	66.9	71	74.0	3.9695		0	0	2		0	2		0
7/31/2007	2100	71.9	66.9	84	70.7	0.6768		0	0	2		0	2		0
7/31/2007	2200	69	66	89	68.3	0		0	2	2		0	0		0
7/31/2007	2300	66.9	66	96	66.7	0		0	2	0		0	0		0
8/1/2007	0	66	64.9	96	65.8	0		0	2	0		0	0		0
8/1/2007	100	66	64.9	96	65.8	0		0	2	0		0	0		0
8/1/2007	200	66	64.9	96	65.8	0		0	2	0		0	0		0
8/1/2007	300	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/1/2007	400	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/1/2007	500	64.9	62.9	93	64.6	-0.36565		0	2	0		0	0		0

8/1/2007	600	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
8/1/2007	700	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/1/2007	800	69	66	89	68.3	0		0	2	2		0	0		0
8/1/2007	900	73	64.9	75	70.9	0.9375	86.695	1	0	2	41.695	1	2	13.695	1
8/1/2007	1000	78.9	66	64	74.8	4.7618		0	0	2		0	2		0
8/1/2007	1100	82.9	64	52	76.3	6.3264		0	0	2		0	2		0
8/1/2007	1200	84.9	64	49	77.4	7.35455		0	0	2		0	2		0
8/1/2007	1300	87.9	62	42	78.4	8.3619		0	-1	2		0	2		0
8/1/2007	1400	91	64.9	42	80.5	10.473		0	-1	2		0	2		0
8/1/2007	1500	89.9	62.9	40	79.4	9.373		0	-1	2		0	2		0
8/1/2007	1600	91	62	38	79.7	9.747		0	-1	2		0	2		0
8/1/2007	1700	91	64	40	80.1	10.11		0	-1	2		0	2		0
8/1/2007	1800	89.9	62.9	40	79.4	9.373		0	-1	2		0	2		0
8/1/2007	1900	86	66.9	53	78.8	8.762		0	-1	2		0	2		0
8/1/2007	2000	78.9	69	71	75.6	5.56645		0	0	2		0	2		0
8/1/2007	2100	75	68	78	72.9	2.943		0	0	2		0	2		0
8/1/2007	2200	71	68	90	70.3	0.285		0	0	2		0	2		0
8/1/2007	2300	69	66.9	92	68.5	0		0	2	2		0	0		0
8/2/2007	0	66.9	66	96	66.7	0		0	2	0		0	0		0
8/2/2007	100	66	64.9	96	65.8	0		0	2	0		0	0		0
8/2/2007	200	66	64	93	65.7	0		0	2	0		0	0		0
8/2/2007	300	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/2/2007	400	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/2/2007	500	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
8/2/2007	600	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
8/2/2007	700	64	64	100	64.0	-1		0	2	0		0	0		0
8/2/2007	800	69.9	66	87	69.0	0		0	2	2		0	0		0
8/2/2007	900	73.9	66.9	78	72.0	1.9761	103.0869	1	0	2	59.0869	1	2	27.0869	1
8/2/2007	1000	80	66.9	64	75.6	5.644		0	0	2		0	2		0
8/2/2007	1100	84	66.9	56	77.7	7.708		0	0	2		0	2		0
8/2/2007	1200	87	66.9	51	79.2	9.1845		0	-1	2		0	2		0
8/2/2007	1300	91.9	66	42	81.1	11.0859		0	-1	2		0	2		0
8/2/2007	1400	93.9	60.9	33	80.7	10.67085		0	-1	2		0	2		0
8/2/2007	1500	95	60.9	32	81.2	11.162		0	-1	2		0	2		0
8/2/2007	1600	93.9	62.9	36	81.3	11.2632		0	-1	2		0	2		0
8/2/2007	1700	93	62	35	80.5	10.4875		0	-1	2		0	2		0
8/2/2007	1800	91.9	62	37	80.2	10.15365		0	-1	2		0	2		0
8/2/2007	1900	87.9	62	42	78.4	8.3619		0	-1	2		0	2		0
8/2/2007	2000	80	66.9	64	75.6	5.644		0	0	2		0	2		0
8/2/2007	2100	73.9	66.9	78	72.0	1.9761		0	0	2		0	2		0
8/2/2007	2200	71	68	90	70.3	0.285		0	0	2		0	2		0
8/2/2007	2300	71	66.9	86	70.0	0		0	0	2		0	2		0
8/3/2007	0	69	66.9	92	68.5	0		0	2	2		0	0		0
8/3/2007	100	68	66	93	67.6	0		0	2	2		0	0		0
8/3/2007	200	66.9	64.9	93	66.6	0		0	2	0		0	0		0
8/3/2007	300	66	64.9	96	65.8	0		0	2	0		0	0		0

8/3/2007	400	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
8/3/2007	500	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/3/2007	600	64	62.9	96	63.9	-1.132		0	2	0		0	0		0
8/3/2007	700	66.9	64.9	93	66.6	0		0	2	0		0	0		0
8/3/2007	800	71	66.9	86	70.0	0		0	0	2		0	2		0
8/3/2007	900	77	68	73	74.2	4.1785	121.8496	1	0	2	75.84955	1	2	41.84955	1
8/3/2007	1000	80.9	68	64	76.4	6.3658		0	0	2		0	2		0
8/3/2007	1100	84.9	68	56	78.4	8.3902		0	0	2		0	2		0
8/3/2007	1200	87.9	68	51	79.8	9.84195		0	-1	2		0	2		0
8/3/2007	1300	91	68	46	81.2	11.199		0	-1	2		0	2		0
8/3/2007	1400	91	68	46	81.2	11.199		0	-1	2		0	2		0
8/3/2007	1500	93	66	41	81.6	11.6425		0	-1	2		0	2		0
8/3/2007	1600	93.9	60.9	33	80.7	10.67085		0	-1	2		0	2		0
8/3/2007	1700	91.9	64.9	41	80.9	10.89945		0	-1	2		0	2		0
8/3/2007	1800	91	62	38	79.7	9.747		0	-1	2		0	2		0
8/3/2007	1900	87	66.9	51	79.2	9.1845		0	-1	2		0	2		0
8/3/2007	2000	84.9	68	56	78.4	8.3902		0	0	2		0	2		0
8/3/2007	2100	75.9	69.9	81	74.0	4.02945		0	0	2		0	2		0
8/3/2007	2200	73	69	87	71.9	1.9275		0	0	2		0	2		0
8/3/2007	2300	71.9	69	90	71.1	1.1355		0	0	2		0	2		0
8/4/2007	0	71	68	90	70.3	0.285		0	0	2		0	2		0
8/4/2007	100	69.9	68	93	69.4	0		0	2	2		0	0		0
8/4/2007	200	69.9	68	93	69.4	0		0	2	2		0	0		0
8/4/2007	300	69	66.9	92	68.5	0		0	2	2		0	0		0
8/4/2007	400	66.9	66	96	66.7	0		0	2	0		0	0		0
8/4/2007	500	66	64.9	96	65.8	0		0	2	0		0	0		0
8/4/2007	600	66.5	65.5	96	66.3	0		0	2	0		0	0		0
8/4/2007	700	66.9	66	96	66.7	0		0	2	0		0	0		0
8/4/2007	800	73.9	69.9	87	72.8	2.76315		0	0	2		0	2		0
8/4/2007	900	78.9	66.9	66	75.0	4.9917	64.85443	1	0	2	19.85443	1	2	-10.1456	0
8/4/2007	1000	82.9	62.9	50	76.1	6.0525		0	0	2		0	2		0
8/4/2007	1100	86	60	41	76.9	6.914		0	-1	2		0	2		0
8/4/2007	1200	89	57.9	35	77.9	7.9175		0	-1	2		0	2		0
8/4/2007	1300	91	57	31	78.5	8.4765		0	-1	2		0	2		0
8/4/2007	1400	93	53	25	78.6	8.5625		0	-1	2		0	2		0
8/4/2007	1500	93.9	48	20	78.1	8.104		0	-1	2		0	2		0
8/4/2007	1600	93.9	48.9	21	78.3	8.30145		0	-1	2		0	2		0
8/4/2007	1700	93.9	50	22	78.5	8.4989		0	-1	2		0	2		0
8/4/2007	1800	92.5	50.5	23.5	78.0	7.984125		0	-1	2		0	2		0
8/4/2007	1900	91	51	25	77.4	7.3875		0	-1	2		0	2		0
8/4/2007	2000	77	60	55	72.3	2.2975		0	0	2		0	2		0
8/4/2007	2100	73	59	61	69.8	0		0	0	2		0	2		0
8/4/2007	2200	73.9	57	55	70.0	0		0	0	2		0	2		0
8/4/2007	2300	71.9	57.9	61	68.9	0		0	0	2		0	2		0
8/5/2007	0	69.9	60	70	67.9	0		0	2	2		0	0		0
8/5/2007	100	68	59	72	66.5	0		0	2	2		0	0		0

8/5/2007	200	66	57.9	75	64.9	-0.1		0	2	0		0	0		0
8/5/2007	300	64	57.9	80	63.3	-1.66		0	2	0		0	0		0
8/5/2007	400	60.9	57	86	60.7	-4.3233		0	2	0		0	0		0
8/5/2007	500	60	57	89	59.9	-5.121		0	2	0		0	0		0
8/5/2007	600	60	55.9	86	59.8	-5.154		0	2	0		0	0		0
8/5/2007	700	60.9	57.9	89	60.7	-4.27545		0	2	0		0	0		0
8/5/2007	800	69	57.9	67	67.0	0		0	2	2		0	0		0
8/5/2007	900	71.9	57	59	68.8	0	49.57965	1	0	2	-18.4204	0	2	-44.4204	0
8/5/2007	1000	75	57	53	70.6	0.6055		0	0	2		0	2		0
8/5/2007	1100	78	57	48	72.3	2.28		0	0	2		0	2		0
8/5/2007	1200	82	55.9	40	74.1	4.08		0	0	2		0	2		0
8/5/2007	1300	86	57	37	76.3	6.298		0	-1	2		0	2		0
8/5/2007	1400	86	57.9	38	76.5	6.452		0	-1	2		0	2		0
8/5/2007	1500	84.9	57.9	39	75.9	5.87505		0	0	2		0	2		0
8/5/2007	1600	84	60	44	76.0	5.992		0	0	2		0	2		0
8/5/2007	1700	82.9	60.9	47	75.6	5.64165		0	0	2		0	2		0
8/5/2007	1800	82	62	50	75.4	5.4		0	0	2		0	2		0
8/5/2007	1900	78.9	64.9	62	74.5	4.5319		0	0	2		0	2		0
8/5/2007	2000	73.9	66.9	78	72.0	1.9761		0	0	2		0	2		0
8/5/2007	2100	71.9	66	81	70.4	0.44745		0	0	2		0	2		0
8/5/2007	2200	69.9	66.9	90	69.2	0		0	2	2		0	0		0
8/5/2007	2300	69	66.9	92	68.5	0		0	2	2		0	0		0
8/6/2007	0	69	66.9	92	68.5	0		0	2	2		0	0		0
8/6/2007	100	69	66.9	92	68.5	0		0	2	2		0	0		0
8/6/2007	200	69	68	96	68.8	0		0	2	2		0	0		0
8/6/2007	300	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	400	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	500	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	600	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	700	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	800	69.9	68	93	69.4	0		0	2	2		0	0		0
8/6/2007	900	71.9	69	90	71.1	1.1355	122.8322	1	0	2	68.8322	1	2	30.8322	1
8/6/2007	1000	73.9	69	84	72.5	2.5008		0	0	2		0	2		0
8/6/2007	1100	75.9	69	79	73.8	3.83255		0	0	2		0	2		0
8/6/2007	1200	78	69.9	76	75.4	5.36		0	0	2		0	2		0
8/6/2007	1300	82	71	69	77.9	7.908		0	0	2		0	2		0
8/6/2007	1400	82.9	71.9	69	78.7	8.65455		0	0	2		0	2		0
8/6/2007	1500	84	71.9	67	79.3	9.281		0	0	2		0	2		0
8/6/2007	1600	87.9	73	61	81.5	11.48645		0	-1	2		0	2		0
8/6/2007	1700	87.9	71.9	59	81.2	11.15755		0	-1	2		0	2		0
8/6/2007	1800	87.9	73	61	81.5	11.48645		0	-1	2		0	2		0
8/6/2007	1900	87.9	73	61	81.5	11.48645		0	-1	2		0	2		0
8/6/2007	2000	84.9	73	67	80.0	10.01765		0	0	2		0	2		0
8/6/2007	2100	77	73.9	90	76.0	5.955		0	0	2		0	2		0
8/6/2007	2200	82	73	74	78.6	8.568		0	0	2		0	2		0
8/6/2007	2300	78.9	73	82	76.8	6.8309		0	0	2		0	2		0

8/7/2007	0	73	71	93	72.4	2.4225		0	0	2		0	2		0
8/7/2007	100	73	71.9	96	72.7	2.67		0	0	2		0	2		0
8/7/2007	200	71	69.9	96	70.7	0.714		0	0	2		0	2		0
8/7/2007	300	69.9	69	96	69.6	0		0	2	2		0	0		0
8/7/2007	400	69	68	96	68.8	0		0	2	2		0	0		0
8/7/2007	500	69	68	96	68.8	0		0	2	2		0	0		0
8/7/2007	600	69	68	96	68.8	0		0	2	2		0	0		0
8/7/2007	700	69	66.9	92	68.5	0		0	2	2		0	0		0
8/7/2007	800	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/7/2007	900	75.9	71.9	87	74.6	4.62015	192.5502	1	0	2	150.5502	1	2	102.5502	1
8/7/2007	1000	80.9	71	71	77.2	7.24745		0	0	2		0	2		0
8/7/2007	1100	82.9	71.9	69	78.7	8.65455		0	0	2		0	2		0
8/7/2007	1200	86	73	65	80.6	10.61		0	-1	2		0	2		0
8/7/2007	1300	87.9	73.9	63	81.8	11.81535		0	-1	2		0	2		0
8/7/2007	1400	89	73	59	82.0	12.0095		0	-1	2		0	2		0
8/7/2007	1500	89	71.9	57	81.7	11.6685		0	-1	2		0	2		0
8/7/2007	1600	89	71.9	57	81.7	11.6685		0	-1	2		0	2		0
8/7/2007	1700	87	73	63	81.1	11.0985		0	-1	2		0	2		0
8/7/2007	1800	84	75.9	76	80.6	10.568		0	0	2		0	2		0
8/7/2007	1900	82.9	75	77	79.8	9.75015		0	0	2		0	2		0
8/7/2007	2000	80	75.9	87	78.4	8.427		0	0	2		0	2		0
8/7/2007	2100	78	75.9	93	77.2	7.23		0	0	2		0	2		0
8/7/2007	2200	77	75.9	96	76.6	6.582		0	0	2		0	2		0
8/7/2007	2300	77	77	100	77.0	7		0	0	2		0	2		0
8/8/2007	0	77	75.9	96	76.6	6.582		0	0	2		0	2		0
8/8/2007	100	77	75.9	96	76.6	6.582		0	0	2		0	2		0
8/8/2007	200	75.9	75	97	75.6	5.60465		0	0	2		0	2		0
8/8/2007	300	77	75	93	76.3	6.2685		0	0	2		0	2		0
8/8/2007	400	77	75	93	76.3	6.2685		0	0	2		0	2		0
8/8/2007	500	75.9	75	97	75.6	5.60465		0	0	2		0	2		0
8/8/2007	600	75.9	73.9	93	75.2	5.21085		0	0	2		0	2		0
8/8/2007	700	75.9	73.9	93	75.2	5.21085		0	0	2		0	2		0
8/8/2007	800	77	75	93	76.3	6.2685		0	0	2		0	2		0
8/8/2007	900	80	75	84	78.1	8.064	159.8826	1	0	2	119.8826	1	2	83.8826	1
8/8/2007	1000	84	75.9	76	80.6	10.568		0	0	2		0	2		0
8/8/2007	1100	87	75	67	81.7	11.7365		0	-1	2		0	2		0
8/8/2007	1200	89	73.9	61	82.4	12.3505		0	-1	2		0	2		0
8/8/2007	1300	89.9	71.9	55	82.0	12.00475		0	-1	2		0	2		0
8/8/2007	1400	91	71	52	82.3	12.288		0	-1	2		0	2		0
8/8/2007	1500	93	69.9	47	82.8	12.7975		0	-1	2		0	2		0
8/8/2007	1600	93.9	69.9	45	83.0	13.04025		0	-1	2		0	2		0
8/8/2007	1700	91.9	69	47	82.0	12.01815		0	-1	2		0	2		0
8/8/2007	1800	93	69.9	47	82.8	12.7975		0	-1	2		0	2		0
8/8/2007	1900	91.9	69	47	82.0	12.01815		0	-1	2		0	2		0
8/8/2007	2000	86	71	61	80.0	9.994		0	-1	2		0	2		0
8/8/2007	2100	84.9	69	59	78.8	8.83405		0	0	2		0	2		0

8/8/2007	2200	78.9	69.9	73	75.8	5.79635		0	0	2		0	2		0
8/8/2007	2300	75	69.9	84	73.5	3.504		0	0	2		0	2		0
8/9/2007	0	73	69.9	90	72.2	2.175		0	0	2		0	2		0
8/9/2007	100	71	69	93	70.5	0.4995		0	0	2		0	2		0
8/9/2007	200	68	66.9	96	67.8	0		0	2	2		0	0		0
8/9/2007	300	66.9	66	96	66.7	0		0	2	0		0	0		0
8/9/2007	400	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
8/9/2007	500	64.9	64.9	100	64.9	-0.1		0	2	0		0	0		0
8/9/2007	600	64.9	64	96	64.7	-0.2518		0	2	0		0	0		0
8/9/2007	700	66	64.9	96	65.8	0		0	2	0		0	0		0
8/9/2007	800	71	66.9	86	70.0	0		0	0	2		0	2		0
8/9/2007	900	75.9	68	76	73.5	3.5372	87.15665	1	0	2	39.15665	1	2	-8.84335	0
8/9/2007	1000	80	66	62	75.4	5.402		0	0	2		0	2		0
8/9/2007	1100	80.9	66.9	62	76.1	6.1139		0	0	2		0	2		0
8/9/2007	1200	84	66.9	56	77.7	7.708		0	0	2		0	2		0
8/9/2007	1300	78.9	69	71	75.6	5.56645		0	0	2		0	2		0
8/9/2007	1400	77	69.9	78	74.7	4.701		0	0	2		0	2		0
8/9/2007	1500	78	69.9	76	75.4	5.36		0	0	2		0	2		0
8/9/2007	1600	78	69.9	76	75.4	5.36		0	0	2		0	2		0
8/9/2007	1700	78.9	71	76	76.1	6.1412		0	0	2		0	2		0
8/9/2007	1800	77	71.9	84	75.3	5.328		0	0	2		0	2		0
8/9/2007	1900	75.9	71.9	87	74.6	4.62015		0	0	2		0	2		0
8/9/2007	2000	75	71	87	73.8	3.7845		0	0	2		0	2		0
8/9/2007	2100	73	71.9	96	72.7	2.67		0	0	2		0	2		0
8/9/2007	2200	73	71	93	72.4	2.4225		0	0	2		0	2		0
8/9/2007	2300	73	71	93	72.4	2.4225		0	0	2		0	2		0
8/10/2007	0	73	71	93	72.4	2.4225		0	0	2		0	2		0
8/10/2007	100	73	71	93	72.4	2.4225		0	0	2		0	2		0
8/10/2007	200	73	69.9	90	72.2	2.175		0	0	2		0	2		0
8/10/2007	300	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/10/2007	400	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/10/2007	500	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/10/2007	600	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/10/2007	700	71.9	69.9	93	71.4	1.36485		0	0	2		0	2		0
8/10/2007	800	73	69.9	90	72.2	2.175		0	0	2		0	2		0
8/10/2007	900	77	71.9	84	75.3	5.328	34.83825	1	0	2	-15.1618	0	2	-41.1618	0
8/10/2007	1000	78.9	71	76	76.1	6.1412		0	0	2		0	2		0
8/10/2007	1100	82.9	68	60	77.4	7.422		0	0	2		0	2		0
8/10/2007	1200	82	66.9	60	76.7	6.72		0	0	2		0	2		0
8/10/2007	1300	82	68	62	77.0	6.984		0	0	2		0	2		0
8/10/2007	1400	84	66.9	56	77.7	7.708		0	0	2		0	2		0
8/10/2007	1500	82.9	66	56	76.9	6.8742		0	0	2		0	2		0
8/10/2007	1600	82	64.9	56	76.2	6.192		0	0	2		0	2		0
8/10/2007	1700	82	64.9	56	76.2	6.192		0	0	2		0	2		0
8/10/2007	1800	80	64	58	74.9	4.918		0	0	2		0	2		0
8/10/2007	1900	78	64	62	73.8	3.82		0	0	2		0	2		0

8/10/2007	2000	75	64	68	72.0	2.008		0	0	2		0	2		0
8/10/2007	2100	71.9	64	76	70.1	0.0652		0	0	2		0	2		0
8/10/2007	2200	68	62	81	67.0	0		0	2	2		0	0		0
8/10/2007	2300	64.9	60	84	64.3	-0.7072		0	2	0		0	0		0
8/11/2007	0	62.9	60	90	62.6	-2.3695		0	2	0		0	0		0
8/11/2007	100	64.9	60	84	64.3	-0.7072		0	2	0		0	0		0
8/11/2007	200	64	59	83	63.4	-1.561		0	2	0		0	0		0
8/11/2007	300	62	57.9	86	61.7	-3.308		0	2	0		0	0		0
8/11/2007	400	59	57	93	59.0	-6.0385		0	2	0		0	0		0
8/11/2007	500	57.9	57	96	57.9	-7.0978		0	2	0		0	0		0
8/11/2007	600	57.9	55.9	93	57.9	-7.09615		0	2	0		0	0		0
8/11/2007	700	60	57.9	92	59.9	-5.088		0	2	0		0	0		0
8/11/2007	800	64	59	83	63.4	-1.561		0	2	0		0	0		0
8/11/2007	900	68	60	75	66.6	0	-18.0184	0	2	2	-65.0184	0	0	-87.0184	0
8/11/2007	1000	71.9	60.9	68	69.5	0		0	0	2		0	2		0
8/11/2007	1100	75.9	60.9	59	71.9	1.86355		0	0	2		0	2		0
8/11/2007	1200	78.9	62.9	57	74.0	3.95715		0	0	2		0	2		0
8/11/2007	1300	82	62	50	75.4	5.4		0	0	2		0	2		0
8/11/2007	1400	82.9	60.9	47	75.6	5.64165		0	0	2		0	2		0
8/11/2007	1500	86	60	41	76.9	6.914		0	-1	2		0	2		0
8/11/2007	1600	86	57	37	76.3	6.298		0	-1	2		0	2		0
8/11/2007	1700	87	55.9	34	76.5	6.473		0	-1	2		0	2		0
8/11/2007	1800	84.9	53	33	75.0	4.98735		0	0	2		0	2		0
8/11/2007	1900	84	53	34	74.6	4.562		0	0	2		0	2		0
8/11/2007	2000	71.9	60.9	68	69.5	0		0	0	2		0	2		0
8/11/2007	2100	66	60.9	83	65.3	0		0	2	0		0	0		0
8/11/2007	2200	62.9	60.9	93	62.7	-2.28865		0	2	0		0	0		0
8/11/2007	2300	62	60	93	61.8	-3.154		0	2	0		0	0		0
8/12/2007	0	60	59	96	60.0	-5.044		0	2	0		0	0		0
8/12/2007	100	59	57.9	96	59.0	-6.022		0	2	0		0	0		0
8/12/2007	200	59	57	93	59.0	-6.0385		0	2	0		0	0		0
8/12/2007	300	57	55.9	96	57.0	-7.978		0	2	0		0	0		0
8/12/2007	400	57.9	55.9	93	57.9	-7.09615		0	2	0		0	0		0
8/12/2007	500	55.9	55	96	55.9	-9.0538		0	2	0		0	0		0
8/12/2007	600	57	55.9	96	57.0	-7.978		0	2	0		0	0		0
8/12/2007	700	57	57	100	57.0	-8		0	2	0		0	0		0
8/12/2007	800	64	60	86	63.5	-1.462		0	2	0		0	0		0
8/12/2007	900	68	62	81	67.0	0	72.2578	1	2	2	20.2578	1	0	-11.7422	0
8/12/2007	1000	75	62	64	71.6	1.634		0	0	2		0	2		0
8/12/2007	1100	78.9	60.9	54	73.6	3.6123		0	0	2		0	2		0
8/12/2007	1200	82.9	62	49	75.9	5.91555		0	0	2		0	2		0
8/12/2007	1300	84.9	62.9	47	77.1	7.05865		0	0	2		0	2		0
8/12/2007	1400	84	60.9	45	76.1	6.135		0	0	2		0	2		0
8/12/2007	1500	87.9	62	42	78.4	8.3619		0	-1	2		0	2		0
8/12/2007	1600	87	59	38	77.1	7.111		0	-1	2		0	2		0
8/12/2007	1700	89	59	36	78.1	8.088		0	-1	2		0	2		0

8/12/2007	1800	86	60.9	43	77.2	7.222		0	-1	2		0	2		0
8/12/2007	1900	84	62	47	76.4	6.421		0	0	2		0	2		0
8/12/2007	2000	78.9	64	60	74.3	4.302		0	0	2		0	2		0
8/12/2007	2100	80.9	62	52	74.9	4.8544		0	0	2		0	2		0
8/12/2007	2200	78.9	60.9	54	73.6	3.6123		0	0	2		0	2		0
8/12/2007	2300	78	62	57	73.3	3.27		0	0	2		0	2		0
8/13/2007	0	73.9	64	71	71.4	1.36395		0	0	2		0	2		0
8/13/2007	100	71	66	84	69.9	0		0	0	2		0	2		0
8/13/2007	200	69.9	66.9	90	69.2	0		0	2	2		0	0		0
8/13/2007	300	68	64.9	89	67.4	0		0	2	2		0	0		0
8/13/2007	400	66	64	93	65.7	0		0	2	0		0	0		0
8/13/2007	500	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
8/13/2007	600	62.9	60.9	93	62.7	-2.28865		0	2	0		0	0		0
8/13/2007	700	62.9	62	96	62.8	-2.2078		0	2	0		0	0		0
8/13/2007	800	69.9	64	81	68.7	0		0	2	2		0	0		0
8/13/2007	900	77	62	59	72.7	2.7155	-31.8728	0	0	2	-72.8728	0	2	-96.8728	0
8/13/2007	1000	78.9	60.9	54	73.6	3.6123		0	0	2		0	2		0
8/13/2007	1100	82.9	55.9	39	74.5	4.54605		0	0	2		0	2		0
8/13/2007	1200	86	55	34	75.8	5.836		0	-1	2		0	2		0
8/13/2007	1300	87	57	36	76.8	6.792		0	-1	2		0	2		0
8/13/2007	1400	89	55.9	32	77.4	7.406		0	-1	2		0	2		0
8/13/2007	1500	86	53.9	33	75.7	5.682		0	-1	2		0	2		0
8/13/2007	1600	89.9	53	28	77.3	7.2676		0	-1	2		0	2		0
8/13/2007	1700	87	57	36	76.8	6.792		0	-1	2		0	2		0
8/13/2007	1800	86	55	34	75.8	5.836		0	-1	2		0	2		0
8/13/2007	1900	82.9	53	35	74.0	3.99825		0	0	2		0	2		0
8/13/2007	2000	78.9	51.9	39	71.9	1.88805		0	0	2		0	2		0
8/13/2007	2100	66.9	55.9	67	65.3	0		0	2	0		0	0		0
8/13/2007	2200	62.9	57	80	62.4	-2.639		0	2	0		0	0		0
8/13/2007	2300	62.9	57	80	62.4	-2.639		0	2	0		0	0		0
8/14/2007	0	60	55.9	86	59.8	-5.154		0	2	0		0	0		0
8/14/2007	100	55.9	53.9	93	56.0	-9.01915		0	2	0		0	0		0
8/14/2007	200	55.9	53.9	93	56.0	-9.01915		0	2	0		0	0		0
8/14/2007	300	55	53.9	96	55.1	-9.934		0	2	0		0	0		0
8/14/2007	400	53.9	53	96	54.0	-11.0098		0	2	0		0	0		0
8/14/2007	500	51.9	50	92	52.2	-12.8316		0	2	0		0	0		0
8/14/2007	600	51	50	96	51.2	-13.846		0	2	0		0	0		0
8/14/2007	700	51.9	51	96	52.0	-12.9658		0	2	0		0	0		0
8/14/2007	800	60	55	83	59.8	-5.187		0	2	0		0	0		0
8/14/2007	900	66.9	53.9	63	65.1	0	-71.9589	0	2	0	-119.959	0	0	-141.959	0
8/14/2007	1000	73	53.9	51	69.0	0		0	0	2		0	2		0
8/14/2007	1100	75	53	46	70.0	0		0	0	2		0	2		0
8/14/2007	1200	77	53	43	71.0	1.0435		0	0	2		0	2		0
8/14/2007	1300	80	48	32	71.8	1.772		0	0	2		0	2		0
8/14/2007	1400	80.9	48.9	32	72.3	2.3354		0	0	2		0	2		0
8/14/2007	1500	82	46.9	29	72.6	2.628		0	0	2		0	2		0

8/14/2007	1600	82.9	46.9	28	73.0	3.0396		0	0	2		0	2		0
8/14/2007	1700	82.9	48.9	30	73.3	3.3135		0	0	2		0	2		0
8/14/2007	1800	80.9	53	38	73.1	3.0911		0	0	2		0	2		0
8/14/2007	1900	78.9	53	40	72.0	2.003		0	0	2		0	2		0
8/14/2007	2000	71	55	56	67.9	0		0	0	2		0	2		0
8/14/2007	2100	64	55.9	74	63.1	-1.858		0	2	0		0	0		0
8/14/2007	2200	62.9	57	80	62.4	-2.639		0	2	0		0	0		0
8/14/2007	2300	62	57	83	61.6	-3.374		0	2	0		0	0		0
8/15/2007	0	57.9	55.9	93	57.9	-7.09615		0	2	0		0	0		0
8/15/2007	100	57	55	93	57.0	-7.9615		0	2	0		0	0		0
8/15/2007	200	55.9	55	96	55.9	-9.0538		0	2	0		0	0		0
8/15/2007	300	55	53.9	96	55.1	-9.934		0	2	0		0	0		0
8/15/2007	400	53.9	53	96	54.0	-11.0098		0	2	0		0	0		0
8/15/2007	500	51.9	51	96	52.0	-12.9658		0	2	0		0	0		0
8/15/2007	600	51.9	51	96	52.0	-12.9658		0	2	0		0	0		0
8/15/2007	700	55.9	53.9	93	56.0	-9.01915		0	2	0		0	0		0
8/15/2007	800	62	57.9	86	61.7	-3.308		0	2	0		0	0		0