國立臺灣大學生物資源暨農學院動物科學技術學系

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以隧道式抽風水簾牛舍紓解荷蘭種泌乳牛於臺灣夏季熱緊迫問題之可行性

Feasibility of Heat Stress Alleviation for Holstein Lactating Cows by a tunnel-ventilated, water-padded barn in hot and humid summer in Taiwan

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本論文係蕭宗法君（D90626001）在國立臺灣大學動物科學技術學系所完成之博士學位論文，於民國 100 年 7 月 22 日承下列考試委員審查通過及口試及格，特此證明

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誌　　謝

漫長的十年博士生生活，終於要告一段落了。

有人問我，有何感想？

有人問我，是否值得？

有人問我，這是何苦？

有人問我，如果重來，是否還讀？

漫長的十年博士生生活，我回想做了些甚麼？

前兩年半滿滿抱負，吸取新知，充實自己。

因工作關係，遠離實驗室至西湖拓荒靜思兩年。

靜思兩年後轉調台南總所，開始新牛舍測試、驗收與遷場。

兩個月後通過資格考試，因工作忙碌休學兩年。

同時變更論文題目以配合新的工作性質。

復學後每週四開開心心到學校陪女兒吃早餐。

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中文摘要

夏季高溫高濕的熱緊迫一直是國內泌乳牛性能表現的瓶頸，改善牛舍降溫環境是紓解熱緊迫最有效與最直接的方法，本試驗目的在評估應用隧道式抽風蒸發冷卻牛舍 (簡稱水簾牛舍) 來紓解夏季荷蘭種泌乳牛熱緊迫的可行性。2005 年試驗採用每期 30 日的交叉設計，平均乳量 26.2 kg 的 42 頭泌乳牛分成二組，分別飼養於水簾牛舍或挑高的太子樓牛舍 (簡稱傳統牛舍)。長方形水簾牛舍可飼養 48 頭牛隻，一端設置整排八臺抽風扇，對應牆面設置 L 型整面水簾，兩側以厚塑膠捲簾密閉形成隧道，抽風扇依氣溫升高而啟動，提供牛隻周遭最高風速每秒 1.66 m 與牛舍空氣交換速度每分鐘 2 次，空氣抽入時經過水簾上的流水而降溫；傳統牛舍共懸掛四臺全日開啟的風扇，採食區另設置每日六次每次 30 分鐘的噴水吹風降溫處理。試驗結果顯示，水簾牛舍可以較傳統牛舍降低日間最高舍溫 2.4℃，並減少牛隻曝露於中度熱緊迫狀況 (78 < 溫濕度指數 (THI) ≤ 84) 的時間 2.5 h；但水簾牛舍內持續高的相對濕度 (全日相對溼度 >93%) 與低的風速增加牛隻熱負荷，牛隻在 4 a.m.的呼吸數 (62 *vs.* 50 次/分鐘)、4 a.m.的直腸溫度 (39.58 *vs.* 39.31℃) 及 2 p.m.的直腸溫度 (39.75 *vs.* 39.47℃) 都顯著高於傳統牛舍牛隻，牛隻血液 CO_2 分壓 (41.4 *vs.* 43.8 mmHg) 降低，血液 pH 值顯著增加。同時，水簾牛舍飼養環境顯著減少牛隻的採食活動，使牛隻乾物質採食量降低 7.6% (17.0 kg *vs.* 18.4 kg)，4% 乳脂校正乳量降低 10.1% (23.1 kg *vs.* 25.7 kg)，乳蛋白質濃度也顯著降低，但水簾牛舍環境並不影響瘤胃的消化，牛隻的瘤胃 pH 值、揮發性脂肪酸與氨態氮濃度都相近。為改善水簾牛舍的氣候環境，2006 年增加牛舍內的抽風扇數量，並安裝與傳統牛舍相同的噴水處理，提供白天最高風速 2.38 m/s 與 3.2 次/min 的空氣交換速度，夜間環境估計分別為 1.17 m/s 與 1.4 次/min。2006 年試驗採用一個 3 x 3 拉丁方設計，將 36 頭泌乳牛分組飼養於傳統牛舍、水簾牛舍或水簾+噴水牛舍，試驗每期 21 日。結果顯示，水簾兩組在降低牛舍日間溫度與 THI 的效率高於傳統牛舍，每日增加舍內氣溫 <26℃的時間達 4.2 小時，但全日相對濕度 >96%。水簾兩組牛隻 3 a.m.的呼吸數與體表溫都顯著高於傳統牛舍組牛隻。水簾組牛隻陰道溫度持續高，但噴水兩組牛隻陰道溫度可隨噴水與擠乳處理後明顯下降 0.4 – 0.6℃。三種牛舍環境對牛隻採食活動、瘤胃消化及泌乳性能的影響相近，但水簾兩組牛隻採食量顯著較高，且水簾+噴水組牛隻乳量有高於傳統組的趨勢 (25.4 kg *vs.* 24.7 kg,

P = 0.10)。由 2006 年試驗結果顯示，三種牛舍環境雖仍無法完全紓解泌乳牛熱緊迫，但經由增加風速與噴水降溫處理，水簾兩組牛隻的採食與泌乳都已相當於或優於傳統組牛隻表現，因此水簾牛舍在高濕地區的使用值得繼續研究。除了影響泌乳牛生理反應與泌乳性能，熱緊迫也嚴重影響乳牛的熱季繁殖效率。2005 年調查傳統牛舍與水簾牛舍牛隻的血清助孕素濃度，得知在同期化發情處理過程中，12 頭泌乳牛助孕素濃度相近。於 2007 年熱季將 40 頭泌乳牛分組飼養於傳統牛舍或水簾+噴水牛舍 90 天 (換氣速度 3.2 次/min)，進行兩次前列腺素注射的發情同期化處理。試驗結果顯示，不論在一般傳統牛舍或水簾+噴水牛舍，熱季期間牛隻對標的配種計畫的反應皆不理想，全期試驗每次人工授精受孕率分別為 20.7%與 17.4%，全期懷孕率分別為 30%與 21.1%。收集接續三年期間 (2008 - 2010) 的田間紀錄，以 2 x 2 複因子設計，分析泌乳牛繁殖效率受畜舍降溫處理 (一般傳統牛舍或水簾+噴水牛舍) 及季節 (涼熱兩季) 之影響。結果顯示，泌乳牛熱季 (5 - 10 月) 懷孕率，在一般傳統牛舍或水簾+噴水牛舍分別為 29.0%與 26.4%，全年則分別為 40.2%與 36.3%，無顯著性差異。綜合三次試驗結果，顯示水簾牛舍的高濕度問題可藉由提高風速來減緩，水簾牛舍內再配合噴水降溫處理，可以有效協助牛隻排熱，提高牛隻泌乳性能，但仍無法解決熱季繁殖效率的低落，如何增加牛舍內通氣量與降低相對濕度，為往後繼續努力的方向。

關鍵語：熱緊迫、荷蘭泌乳牛、溼度、隧道抽風水簾牛舍

Abstract

Heat stress from high temperature and humidity is always the bottleneck in enhancing lactation performance of dairy cows in Taiwan. Improving the barn environment is the most effective and direct method to alleviate cow heat stress. The feasibility of heat stress alleviation for Holstein lactating cows by a tunnel-ventilated, water-padded (TP) barn was assessed in this study. In 2005, a crossover designed experiment was conducted for 30 days a period. A total of 42 head of cows with milk yield of 26.2 kg a day were assigned into the TP barn or the conventional barn. The rectangle TP barn has a raising space for 48 head of lactating cows. Eight exhaustive fans and an L shape water-pad were set at the two end walls in the TP barn. Heavy plastic curtains formed both long side walls contributed the tunnel effect. The exhaustive fans would be turned on following the increasing air temperature and provided the highest daytime air speed of 1.66 m per second and air exchange rate of two times per minute. Evaporating water in the pad absorbs heat from the incoming air and cools the air. Four hung fans operated all day long were set in the conventional barn. Additional six 30-min sprinkler cooling cycles a day were arranged along the intake alley. The results indicated that TP barn could effectively cut down 2.4℃ more at the highest daytime temperature, and decreased 2.5 h more for cows suffering the medium heat stress ($78 < THI \leq 84$) than conventional barn did. However, the persistently high relative humidity (> 93%) and low air speed inside the TP barn increased the heat load for cows. Cows raised in the TP barn had the higher 4 a.m. respiration rate (62 *vs*. 50 breaths/min), 4 a.m. rectal temperature (39.58 *vs*. 39.31℃), and 2 p.m. rectal temperature (39.75 *vs*. 39.47℃) than those raised in the convention barn. TP barn environment decreased the partial pressure of CO_2 in cow blood (41.4 *vs*. 43.8 mmHg), thus increased the blood pH. Meanwhile, TP barn environment significantly decreased cow intake activity and resulted in the lower dry matter intake and 4% fat corrected milk yield by 7.6% (17.0 kg *vs*. 18.4 kg) and 10.1% (23.1 kg *vs*. 25.7 kg), respectively. Percentage of milk protein was also decreased. But rumen digestion pattern was kept the same. Diurnal rumen pH, NH_3-N and volatile fatty acid productions were not influenced by barn environments. To improve the TP barn environment, fan numbers were increased and same sprinkling program as that in the conventional barn were applied in 2006. The highest daytime air speed at cow level and air exchange rate reached 2.38 m/s and 3.2 times/min after the modification. Both parameters at night in

the TP barn were estimated to be 1.17 m/s and 1.4 times/min, respectively. In 2006, 36 cows allocated in a 3 x 3 Latin square with 21 days a period were raised in three barn cooling treatments: the conventional barn like in 2005 trial, a TP barn and a TP barn with sprinkler cooling (TP+SP). Both TP barns were more efficient in reducing the daytime temperature and the temperature humidity index. The barn temperature was less than 26°C for an extra 4.2 h per day, but the relative humidity was above 96% in both TP barns. Cows in both TP barns had higher 3 a.m. respiration rates and skin temperatures than cows in the conventional barn. Vaginal temperature was persistently high in cows in the TP barn; in the two barns with sprinkler cooling, vaginal temperature could effectively decreased 0.4 to 0.6°C following the sprinkling and milking. The intake activity, rumen digestion, and milking performance of cows raised in the three environments were similar. Cows in both TP barns ingested more dry matter. Cows in the TP+SP barn tended to produce more milk than those in the conventional barn (25.4 *vs*. 24.7 kg, $P = 0.10$). Although cows' heat stress was not completely alleviated in these three barns, the TP+SP treatment resolved the negative impact of a previous TP barn built in 2004 on intake and milk yield by increasing air speed and using sprinkler cooling. Thus, it is expected that TP+SP barns will be beneficial in areas of high humidity. Except for the physiological responses and milking performance, the reproductive efficacy of cows is also influenced by the environmental heat stress. The serum progesterone levels during synchronization treatment were similar from 12 cows raised in the conventional barn and TP barn in 2005. In 2007 summer, a total of 40 cows were assigned into the conventional barn or the TP+SP barn (air exchange rate of 3.2 times/min) for a period of 90 days. A target breeding program with two consecutive prostaglandin injections at 14-d interval was applied. No matter cows were raised in the conventional barn or the TP+SP barn, responses to prostaglandin treatment of cows in hot summer was not ideal. Conception rate per AI of cows in these two barns were 20.7% and 17.4%, and for the whole period pregnancy rate were 30% and 21.1%, respectively. From 2008 to 2010, reproductive field data of lactating cows were collected. Data were categorized and statistically analyzed in a 2 x 2 factorial design including barn cooling treatments, conventional barn or TP+SP barn, and seasons, cool or hot season. Results showed that conception rate of cows were not affected by the barn treatment. In hot season (May to Oct.), conception rate of cows in conventional barn and TP+SP barn were 29.0% and 26.4%, and were 40.2% and 36.3% for the whole

year, respectively. Results from all three studies suggested that the high humidity problem in TP barn could be mitigated by the higher air speed. The application of sprinkler cooling in TP barn is beneficial for cows to dissipate their body heat so that to promote the milking performance. However, poor reproductive efficacy in the hot summer is not resolved by the TP+SP barn. Adequate air speed and lower humidity are likely to be key factors for further TP barn study.
Key words: heat stress, Holstein lactating cow, humidity, a tunnel-ventilated, water-padded barn

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第一章　緒　　論

1.1 國內酪農業概況

由民國99年農業統計年報 (2010) 統計資料顯示，我國畜牧業總產值達新台幣1,446 億元，約佔農業總產值之 33%，其中牛乳產值為 81.4 億元，約佔整個畜牧業產值的 5.6%。從 2001 年至 2010 年統計資料顯示，牛乳產業結構已有所改變，雖然飼養戶數與總牛頭數都減少，但每戶飼養規模與生產效率都在提升中。酪農戶由 2001 年的 767 戶減少至 2010 年的 571戶 (-26%)，飼養之荷蘭牛頭數也從 133,718 頭下降至 122,983 頭 (-8%)，但平均酪農戶飼養頭數從 174 頭增加至 215 頭 (+24%)，且每頭牛年產乳量也從 5,314公斤增加至 6,097公斤 (+15%) (表1.1)。

表 1.1　自 2001 至 2010 年間台灣酪農戶數、乳牛頭數與產乳量變化

Table 1.1　Dairy farm number, herd size and milk yield from 2001 to 2010 in Taiwan

Year	Dairy farms	Total dairy cattle (head)	Herd size per farm (head)	Total Milking cows (head)	Total annual milk yield (Ton)	Annual milk yield per cow (kg)
2001	767	133,718	174	65,125	345,970	5,312
2002	751	132,957	178	64,517	357,804	5,546
2003	715	132,263	184	59,467	354,421	5,960
2004	674	128,286	190	54,615	322,660	5,908
2005	638	122,457	191	53,151	303,496	5,710
2006	636	123,587	194	52,269	323,165	6,183
2007	619	126,689	205	53,107	322,220	6,067
2008	591	123,115	208	52,566	315,559	6,004
2009	572	121,967	213	53,170	321,781	6,052
2010	571	122,983	215	55,296	336,036	6,097

From Taiwan Agriculture Statistics Yearbook 2010.
(http://www.coa.gov.tw/view.php?catid=23586)。

台灣牛乳生產是採配額制，每年 11 月由乳品廠與其衛星酪農場簽定為期一年之收乳契約，收乳價格皆依照中央畜產會生乳評議委員會所訂定之冬、暖與夏季計價公式，酪農以契約行銷之方式銷售生乳給乳品廠。由於國人鮮乳消費型態，夏季需求較高冬季則銳減，這與來自溫帶的荷蘭種乳牛較不耐熱的生理特性相牴觸，因此造成夏乳不足冬乳過剩的現象。

表 1.2　歷年來生乳收購基準價變動及夏冬期價差 (新台幣)

Table 1.2　Changes of basic prices for raw milk and its difference between hot and cool period from 1976 to 2009 in Taiwan

Year	Basic price for raw milk (NT$/kg)[1]			Price difference (hot vs. cool)
	Hot period	Warm period	Cool period	
1976[2]	9.50		8.20	1.30
1977	11.00		9.00	2.00
1978	12.00		10.00	2.00
1979	14.22		12.22	2.00
1980	16.72		14.72	2.00
1983	18.73		13.24	5.49
1990[3]	20.73	18.73	13.24	7.49
1997	22.73	20.73	15.24	7.49
2002	22.73	20.73	13.74	8.99
2006	22.73	20.73	15.24	7.49
2007	25.73	23.73	18.24	7.49
2009 (12 月)	27.38	25.38	19.89	7.49

	Basic price for raw milk (NT$/kg)[1]			
Year	Hot period	Warm period	Cool period	Price difference (hot vs. cool)

[1]Basic price of raw milk is set on 3.4% milk fat content and 1.0300 specific gravity.

[2]Two-stage pricing: hot period (April to November) and cool period (December to March).

[3]Thre-stage pricing: hot period (June to September), warm period (April, May, October, and November), and cool period (December to March).

為謀改善此種供需不平衡的問題，紓解牛隻夏季熱緊迫的管理就非常重要了，同時夏季生乳收購價格也提高以鼓勵夏乳的生產。生乳收購價格以乳脂率 3.4% 與比重1.0300為基準，並分季計價，由1976年分夏期 (4 - 11月) 與冬期 (12 - 3月) 的二段式計價，再於1990年調整為三段式計價，區分為夏期 (6 - 9月)、暖期 (4, 5, 10, 及11月) 與冬期 (12 - 3月)，目前每公斤夏季生乳價格高於冬季生乳7.49元 (表1.2)。同時在乳量的調整上，各乳廠普遍採用冬夏乳比例之限制，以夏期＋暖期佔總收乳量的67%，冬期則佔33%。

1.2 環境溫度對牛隻體溫恆定之影響

高生產性能畜禽代謝速率快，其產生的熱須要適當的排出以維持體內環境平衡，當熱的產生大於熱的排除就產生熱緊迫 (heat stress)。環境因素如氣溫、相對濕度、太陽輻射與風速等相互影響，當使環境有效溫度 (effective temperature) 高於動物的中溫帶 (thermoneutral zone) 或舒適帶 (comfort zone) 溫度，就會造成熱緊迫 (圖 1.1) (Kadzere *et al*., 2002)。中溫帶簡單的說就是在維持正常的直腸溫度下最少熱生成的環境溫度範圍，泌乳牛的中溫帶介於 5 - 25℃ (Roenfeldt, 1998)。當環境溫度低於低臨界溫度 (lower critical temperature)，家畜必須提高熱生成以維持恆定的體溫，乳牛在不同時期與泌乳量具有不同程度的代謝熱生成，每日產乳量 30 kg 與 20 kg 之泌乳牛，其低臨界溫度分別為 -16℃與 -10℃，而乾乳牛的低臨界溫度則為 2℃ (Hamada, 1971)；若環境溫度高於高臨界溫度 (upper critical temperature)，家畜必須提高蒸發散熱如排汗與喘息，以消散代謝熱生成，維持恆定的體溫，若提高蒸發散熱仍無法順利排除體熱，就會導致牛隻體溫升高，甚至

最嚴重的死亡。泌乳牛之高臨界溫度僅為 25 - 26℃ (Berman *et al*., 1985)，表示當環境溫度高於 26℃時，泌乳牛即須要開始排除多餘體熱，否則即開始承受熱緊迫。

牛隻體熱排除的方式隨外界環境溫度改變，環境溫度較低時，牛隻體熱的排除以非蒸發 (non-evaporative) 的對流(convection)、傳導 (conduction) 與輻射 (radiation) 進行，亦稱為有感熱的排除 (sensible heat loss)；隨著環境溫度的增加，牛隻散熱方式轉換成蒸發式的流汗 (sweating) 與喘氣 (panting)，亦即為潛熱的排除 (latent heat loss) (Kibler and Brody, 1953)，而總熱生成為有感熱與潛熱的總和 (圖1.2, Mount, 1973)。

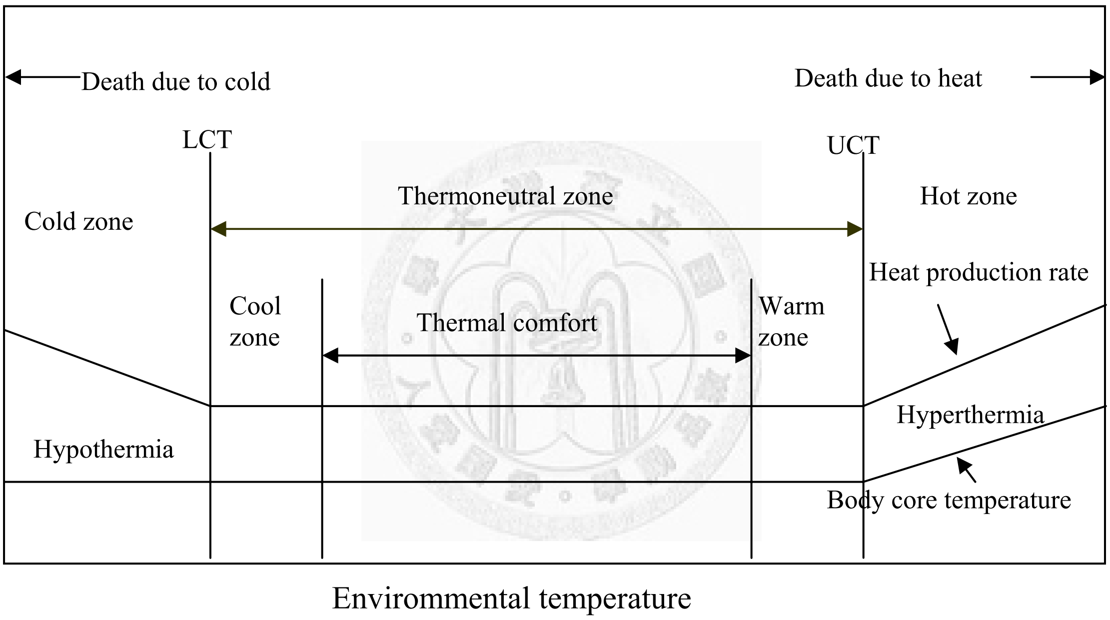

圖 1.1 動物體溫、熱生成與環境溫度之關聯 (Kadzere *et al*., 2002，摘自 Curtis, 1981)。

Figure 1.1 Schematic relationship of the animal's body core temperature, heat production and environmental temperature. LCT, lower critical temperature; UCT, upper critical temperature (Kadzere *et al*., 2002, adapted from Curtis, 1981).

1.3 乳牛熱緊迫程度之評估

在熱緊迫的研究上，可以使用環境狀況或動物表現來評估牛隻所承受的熱緊迫程度。雖然有很多不同意見的討論，由環境氣溫 (temperature, T) 與相對濕度 (relative humidity, RH) 所計算的溫濕度指數 (temperature-humidity index, THI, THI

= 9/5 × T + 32 - 0.55 × (1 - RH) × (9/5 × T - 26), T in ºC and RH in decimal, NOAA, 1976) 是常用的環境熱緊迫指標。THI 公式與劃分方法多元，其中多以 Armstrong (1994) 為基礎，其定義 THI < 72 時，牛隻感受舒適且無緊迫 (no stress)、72 < THI < 78 表示輕微的熱緊迫 (mild stress), 78 < THI < 89 表示牛隻處於中度緊迫狀況、89 < THI < 99 表示嚴重的熱緊迫 (severe stress), THI > 99 為致命狀況 (fatal)；Hahn *et al*. (2009) 將 THI 合併家畜氣候安全指數 (livestock weather safety index)，劃分 THI ≤ 74, 75 – 78, 79 – 83, 及 ≥ 84 四段，分別代表正常、警告、危險及緊急狀況。當牛隻處於熱緊迫狀況下，除了各種適應行為反應外，生產性能表現會明顯低落。環境 THI 值與乳牛乳量及乾物採食量呈負相關，Bouraoui *et al*. (2002) 研究報告指出，當 THI 自 68 增加到 78 時，乳量降低 21%，採食量降低 9.6%；THI 自 69 起，每增加一單位 THI，就會造成 0.41 kg 乳量的下降。

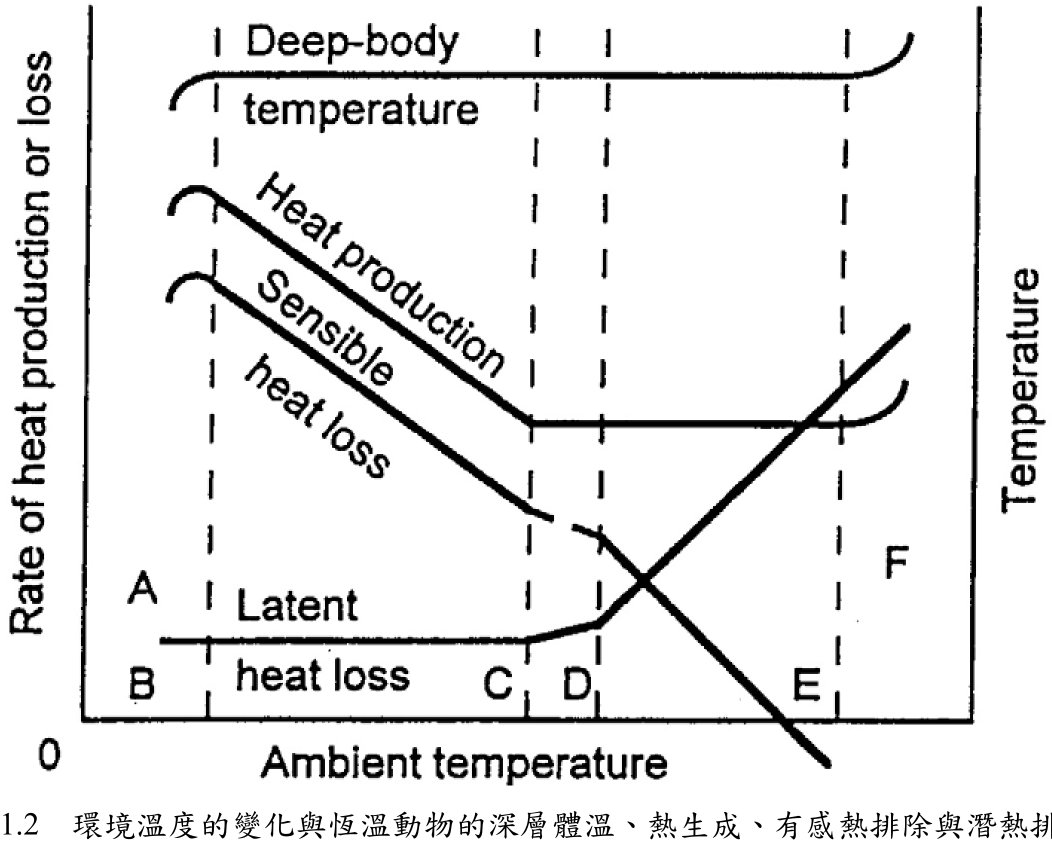

圖 1.2 環境溫度的變化與恆溫動物的深層體溫、熱生成、有感熱排除與潛熱排除間的關係 (Mount, 1973)。

Figure 1.2 Diagram showing the relationships between the deep-body-temperature, total, sensible and latent heat loss in a homoeothermic animal due to the environmental temperature. A: zone of hypothermia; B: temperature at maximum metabolism and beginning hypothermia; C: lower critical temperature; D: temperature of marked increase in latent heat loss; E: temperature of beginning hyperthermia; F: zone of hyperthermia, CD: thermoneutral zone or comfort zone; CE: zone of minimal metabolism; BE: thermoregulatory range (Mount, 1973).

在動物表現方面，呼吸速度 (respiration rate) 與直腸溫度 (rectal temperature) 為良好的熱緊迫指標。研究報告指出，當牛隻處於舒適的中溫帶環境下，每分鐘呼吸速度為 26 次到 35 次 (Reece, 1993)，直腸溫度為 38.0℃到 39.3℃ (Andersson and Jonasson, 1993)。當環境氣溫高於牛隻的中溫帶 (thermoneutral zone)，牛隻的呼吸速度會增加，並與氣溫成高度正相關 (Hahn *et al*., 1997)。中心體溫 (body core temperature) 的量測因量測部位不同而異，包括直腸、耳鼓膜 (ear tympanic membrane)、皮下 (sub-dermal)、瘤胃、陰道及腹腔 (peritoneal cavity)，其中直腸溫最高，鼓膜及腹腔溫度較直腸溫低 0.6℃，且與直腸溫具很高的相關性 (Brown-Brandl *et al*., 2001)。當氣溫高於中溫帶後，牛隻皮下溫度跟隨直腸溫度的變化而變化，但若氣溫等於或低於中溫帶則無此現象 (Hahn *et al*., 1997)，因此在熱緊迫狀況下，利用紅外線溫度計量測牛隻表皮溫度，可與呼吸速度有很高的相關而且相當簡易迅速，同時也是量測牛隻周圍微環境很好的方法 (Collier *et al*., 2006)。

1.4 乳牛對熱緊迫之反應

由於龐大的體軀與快速的代謝速度，泌乳牛對熱緊迫非常敏感，尤其是高產牛。泌乳牛是高生產效率的家畜，每日採食 20 kg 以上的乾物質以生產 25 kg 以上的乳汁。牛隻瘤胃發酵及代謝過程產生大量的熱 (約 4,500 BTU/hr = 13.2 kW/hr，BTU: british thermal unit)，隨著乳量的提高，熱生成也伴隨著增高。Purwanto *et al*. (1990) 指出，高產 (31.6 kg/d) 與中產 (18.5 kg/d) 泌乳牛，其熱生成較乾乳牛熱生成分別高出 48.5% 與 27.3%，因此牛隻為維持體溫的恆定，必須即時得將過多的熱排除。

當牛隻處於熱環境狀況下，可以藉著行為或生理的調適，以增加本身熱的散失或讓熱生成降到最低。Bucklin *et al*. (1991) 指出，泌乳牛反應熱緊迫有以下之方

法 (1) 減少食物的攝食, (2) 增加水分的攝取, (3) 改變代謝速率, (4) 增加呼吸速度, (5) 改變血液中內泌素的含量, 及 (6) 增加身體的溫度等方式來因應熱環境。這些對熱環境的反應，在以下章節中分別以行為、代謝、泌乳與繁殖四方面來探討。

1.4.1 熱緊迫對牛隻行為之影響

行為的調適反應快速且不需要太多的能量，因此成為動物紓解熱緊迫的第一選擇，諸如就近尋求遮蔭，以減少太陽直接照射的熱；由躺臥轉成站立，藉由增加體表面積來提高蒸發與有感熱的散失；增加頭或四肢與冷空氣的表面接觸；減少曝露於陽光的表面積等 (Hillman *et al*., 2005)，進一步，牛隻以增加飲水與排尿、減少採食、增加排汗與喘氣等來散熱 (Bucklin *et al*., 1991; Smith *et al*., 2006a)，若仍無法有效排熱，將導致體溫升高、呼吸次數增加，伴隨著乳量下降與繁殖性能低落等現象 (Ingraham *et al*., 1975; Fuquay, 1981; Igono and Johnson, 1990; West *et al*., 2003)。

當氣溫達 19℃時牛隻呼吸次數開始增加,氣溫達 25℃時開始排汗 (Hahn *et al*., 1997; Maia *et al*., 2005a,b)。高溫環境下，牛隻以流汗為主要散熱方法，但喘氣則比較容易被管理者觀察到，牛隻流汗與喘氣分別完成 85% 與 15% 的蒸發散熱功能 (Maia *et al*., 2005b; Hillman, 2009)。環境氣候除了氣溫外，相對溼度與風速也扮演著舉足輕重的影響因素，牛隻排汗速率受到相對濕度與風速的影響，當相對濕度由 30% 提高到 90% 時，排汗速率由 500 g $H_2O/(m^2h)$ 顯著得降低至 60 g $H_2O/(m^2h)$ (Maia *et al*., 2005b)，經過牛隻體表的風速由 0.2 m/s 提高到 0.9 m/s 時，排汗速率可由 75 g $H_2O/(m^2h)$ 大幅提高到 350 g $H_2O/(m^2h)$，若風速再提高至 2.2 m/s，並不會再增加排汗速率 (Hillman *et al*., 2001)。

牛隻品種的耐熱程度會有差異。澳洲研究團隊在歐洲牛與印度牛之女牛群運輸途中，將溫度監測器埋置於牛隻腹膜腔中，同時觀測牛隻乾物質採食量、飲水量、呼吸速度及心跳速率的變化。結果顯示如圖1.3，歐洲牛採食量與心跳速率隨牛隻體溫升高而下降，但飲水量與呼吸速度則隨牛隻體溫升高而上升；印度牛採食量也隨牛隻體溫升高而下降，飲水量與呼吸速度也隨牛隻體溫升高而上升，但增加的幅度大於歐洲牛，顯示印度牛女牛對體溫升高的行為反應大於歐洲牛女牛，且其心跳速率不受體溫升高的影響 (Beatty *et al*., 2006)。

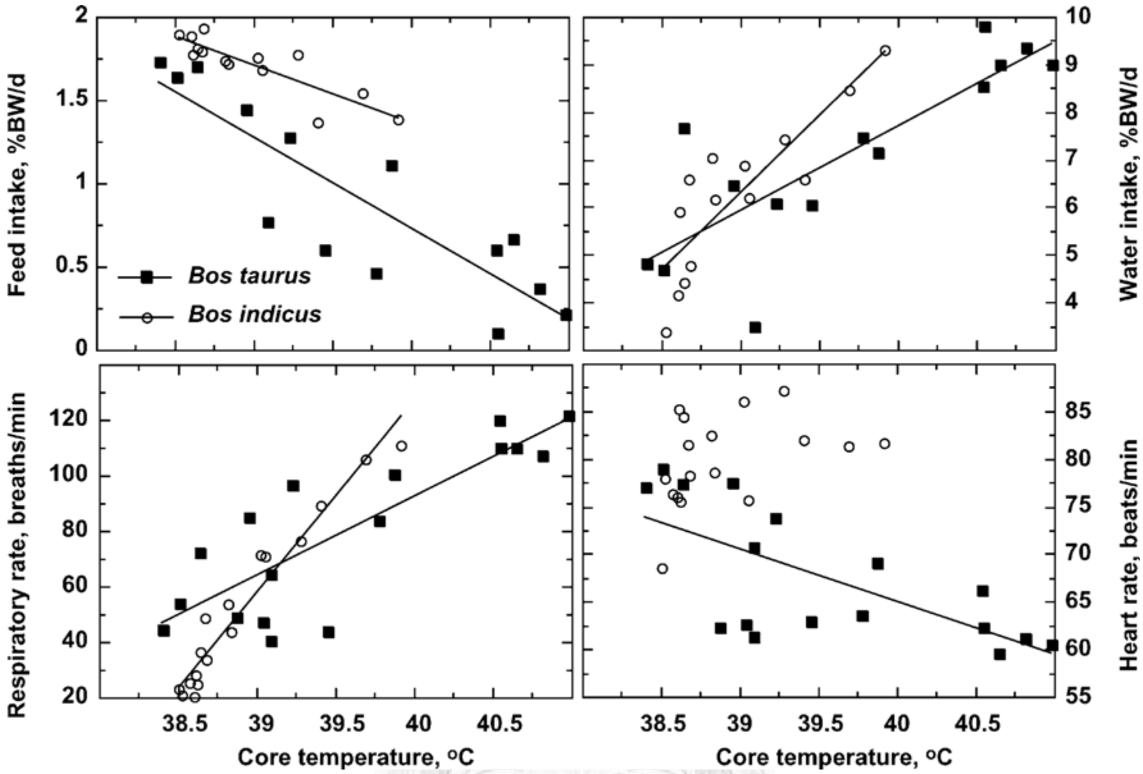

圖 1.3　歐洲牛與印度牛女牛每日平均體溫與其採食量、飲水量、呼吸速度及心跳速率的相關性 (Beatty *et al*., 2006)。

Figure 1.3　Daily average feed intake, water intake, respiratory rate, and heart rate plotted against daily averages of core body temperature for *Bos Taurus* and *Bos indicus* heifers (Beatty *et al*., 2006).

1.4.2 熱緊迫對牛隻代謝之影響

牛隻營養代謝也隨熱緊迫程度有所變化。乳酸鹽脫氫酶 (lactate dehydrogenase, LDH) 是一種葡萄糖代謝過程中的酵素，牛隻血液中的正常值推薦為 < 1,500 U/L (Schmid and von Forstner, 1986)。天門冬胺酸轉胺酶 (aspartate aminotransferase, AST, AST = GOT, glutamic oxaloacetic transaminase) 與丙胺酸轉胺酶 (alanine aminotransferase, ALT, ALT = GPT, glutamic pyruvic transaminase) 參與蛋白質代謝過程中胺基的轉換。當牛隻肝臟受損時，血中 AST 與 ALT 活性會升高，但此二轉胺酶的變化並非只對肝臟專一反應 (not liver-specific)。Abeni *et al*. (2007) 與 Calamari *et al*. (2007) 認為血液生化值可做為快速且可靠的熱緊迫指標，熱季會造成荷蘭牛血漿中葡萄糖濃度的降低，血漿中葡萄糖濃度與一日中最高 THI 值成極顯著的負相關 (P < 0.001)；熱季使血漿中膽固醇濃度與鹼性磷酸酶 (alkaline phosphatase, ALP) 活性顯著降低，二者與 THI 值成直線性的負相關；血漿中肌酸酐 (creatinine) 為蛋白質代謝產物之一，也用為肌肉量的指標，熱季血中濃度的升高可能來自肌肉蛋白質的釋出增加 (Fekry *et al*., 1989)，肌酸酐與牛隻直腸溫成極高的正相關 ($P < 0.001$)。

乳牛長期曝露在高溫環境下，會影響其體內的酸鹼平衡 (West *et al*., 1991)，身體經由化學緩衝作用、呼吸調節血中碳酸及腎臟調節氫離子 (H^+) 或重碳酸根離子 (HCO_3^-) 的排出等三種機制，來維持正常的酸鹼平衡 (Houpt, 1993)。當熱負荷增加時，牛隻須藉由喘氣來提高上呼吸道的蒸發散熱作用，但喘氣使 CO_2 的排出大於生成，CO_2 的排出增加促使 H^+與 HCO_3^-合成碳酸 (H_2CO_3)，因此喘氣雖有助排熱，但也造成呼吸性鹼毒症 (respiratory alkalosis) 現象，即血中 CO_2 分壓降低、HCO_3^-濃度降低及血液 pH 值上升 (Collier *et al*., 1982; Calamari *et al*., 2007)。

1.4.3 熱緊迫對牛隻泌乳之影響

為降低代謝熱的產生，承受熱緊迫的牛隻會很明顯的降低其採食量，因此泌乳量也快速的降低。在很早的年代裡，研究人員已瞭解到環境溫度對生產的嚴重影響，Yeck and Stewart (1959) 推估了荷蘭牛與娟姍牛乳量受環境溫度的影響情形，顯示在環境相對濕度 55 - 70%時，當氣溫在 2 - 24℃範圍內，牛隻乳量可維持 100% 的表現，但一旦氣溫超過 24℃時，乳量開始急遽下降，荷蘭牛乳量下降的速度更大於娟姍牛，當氣溫到達約 35℃時，荷蘭牛乳量只剩約 50%，娟姍牛乳量也只剩下約 62% (圖1.4)。牛隻每日直腸溫超過 39℃達 16 小時以上，則造成乳量下降，即使短期的熱浪，也可以降低 10% 到 20% 的乳量，而且對高產牛更嚴重 (Igono and Johnson, 1990)。 Rodriquez *et al*. (1985) 分析美國 Florida 州農業試驗站 22,972 筆資料後，得知每日氣溫最高溫在 8℃到 29℃範圍時，牛隻乳量不受環境溫度的影響，但 > 29℃後，乳量即快速下降；而乳脂肪與乳蛋白濃度隨著每日最高溫自 8℃增加到 37℃而下降。

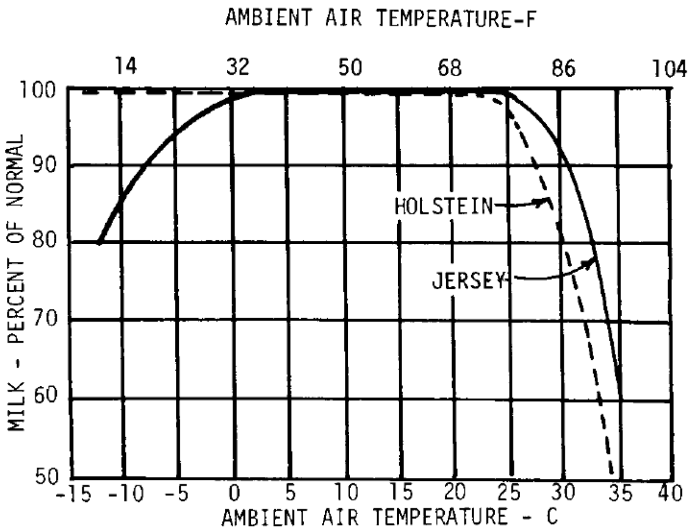

圖 1.4　氣溫對荷蘭牛與娟姍牛乳產量之影響 (Yeck and Stewart, 1959)。

Figure 1.4　Effect of ambient air temperature on milk production in Holstein and Jersey cattle (Yeck and Stewart, 1959).

West *et al*. (2003) 將荷蘭牛與娟姍牛泌乳牛曝露於溫和或溼熱環境下，探討環境溫溼度對牛隻採食量、泌乳量及乳溫之影響。試驗結果指出，乳溫也可做為熱緊迫的指標，乳溫隨氣溫的增加而線性地增加，與下午乳溫相關最高的是當日平均氣溫，而上午乳溫則與當日最低氣溫有高度相關。不論荷蘭牛或娟姍牛，牛隻採食量與乳量都隨著熱緊迫的增加而減少，當日牛隻乾物採食量受兩日前的平均氣溫影響最大，每度氣溫的增加分別造成荷蘭牛與娟珊牛 0.85 kg 與 0.88 kg 採食量的下降 (圖1.5 A)；當日牛隻乳量受兩日前的平均 THI 影響最大，每單位 THI 增加分別造成荷蘭牛與娟珊牛 0.88 kg 與 0.60 kg 乳量的下降 (圖1.5 B)，這篇研究報告確認環境對牛隻的表現確實存在延長的影響力。

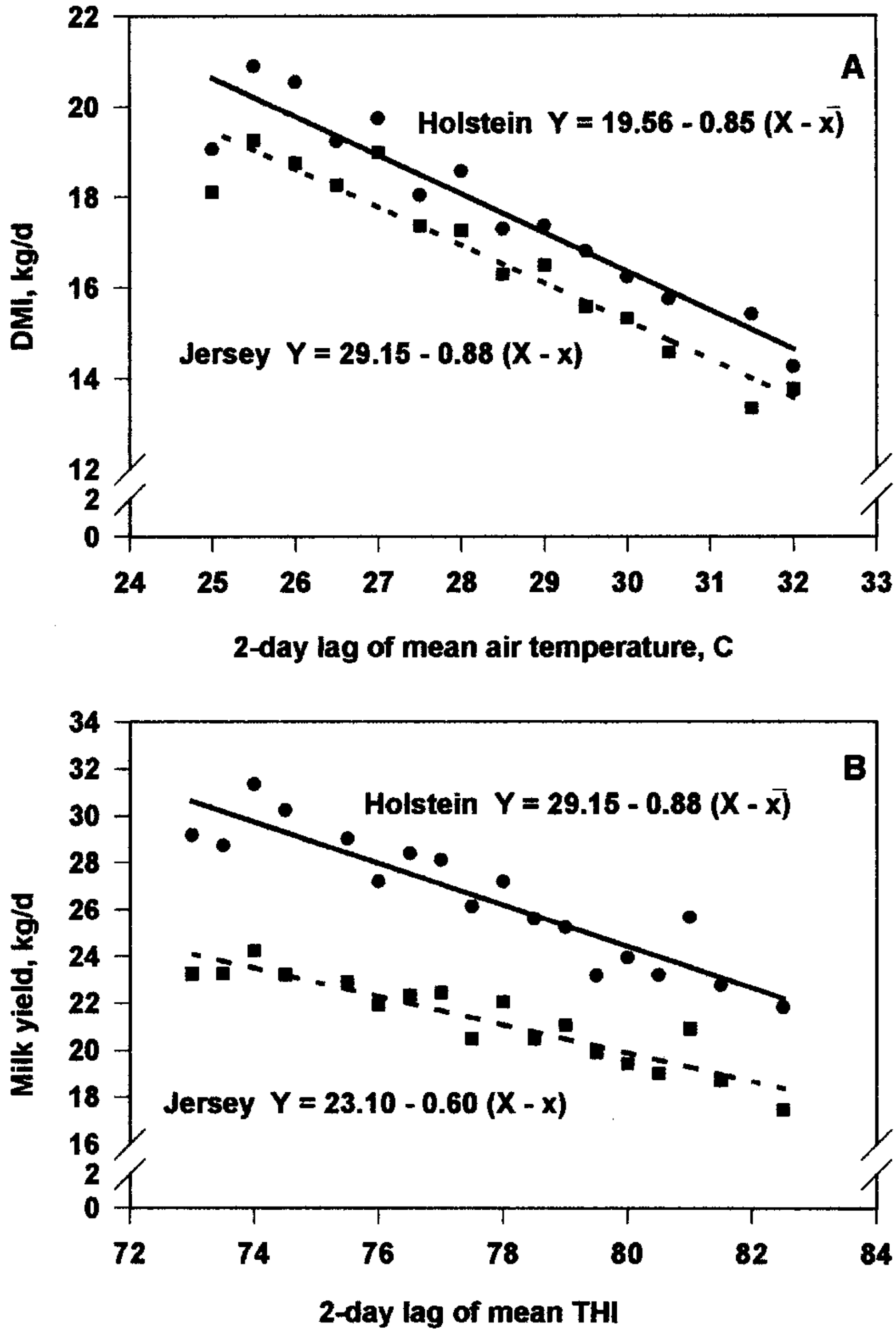

圖 1.5　荷蘭牛 (●) 與娟姍牛 (■) 乾物質採食量與 2 日前平均氣溫 (A) 及泌乳量與 2 日前平均 THI 的相關性 (B) (West *et al*., 2003)。

Figure 1.5　Regressions of DMI on 2-d lag of mean air temperature (A) and milk yield on 2-d lag of mean temperature humidity index (B) for Holstein (●) and Jersey (■) cows (West *et al*., 2003).

1.4.4 熱緊迫對牛隻繁殖之影響

熱緊迫不但影響了牛隻的泌乳，同時也影響牛隻的繁殖性能表現，其影響的機制如圖 1.6。De Rensis and Scaramuzzi (2003) 指陳，熱緊迫對泌乳牛繁殖效率降低之影響並非是經由單一途徑，諸如經由降低乾物質的採食量，間接的抑制由下視丘-腦垂腺系統 (hypothalamo-pituitary system) 所分泌的 GnRH 與 LH；但是是否可以直接的抑制下視丘-腦垂腺系統分泌 GnRH 與 LH 並不清楚；熱緊迫是可以直接的影響子宮環境造成胚的損失與低生育率。

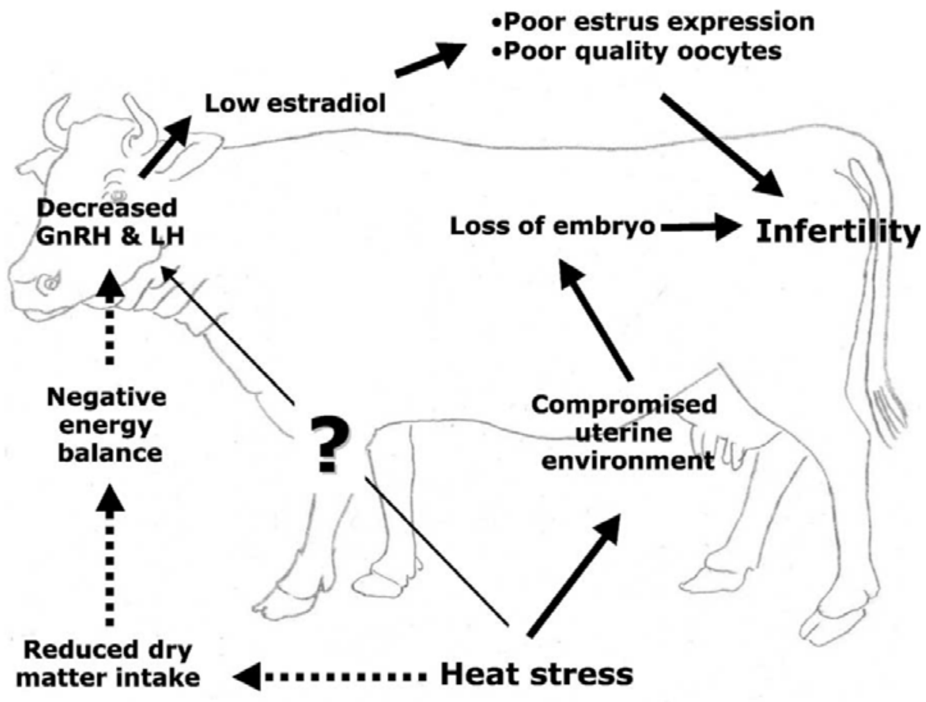

圖 1.6 熱緊迫影響牛隻繁殖功能之可能機制。(De Rensis and Scaramuzzi, 2003)

Figure 1.6 A schematic description of the possible mechanisms for the effect of heat stress on reproduction in the lactating dairy cow. (De Rensis and Scaramuzzi, 2003)

熱緊迫會造成牛隻靜默發情 (silent heat)、乏情 (anoestrus) 與降低發情行為的顯現，因而影響牛隻的繁殖效率。Nobel *et al*. (1997) 指出荷蘭牛每次發情的牛隻駕乘數，冬季約為夏季的 2 倍，分別為 8.6 次與 4.5 次。熱緊迫亦影響牛隻內分泌的分泌形式，熱緊迫降低了排卵素 (luteinizing hormone, LH) 分泌的脈衝與高度 (pulse and amplitude)，這種低的 LH 分泌模式導致優勢濾泡 (dominant follicle) 的

遲滯與延遲排卵，雌素二醇 (oestradiol) 分泌降低也影響發情行為的顯現，因此造成生育率的低落 ((De Rensis and Scaramuzzi, 2003))；同時遲滯的優勢濾泡，產生老化與低品質的卵子，因此降低了懷孕率 (Diskin *et al*., 2002; Bridges *et al*., 2005)。熱緊迫會降低血液中助孕素 (progesterone, P4) 濃度，影響子宮受孕的環境；減少流入母體子宮的血液量，導致子宮溫度的提高，造成胚早期死亡或埋植失敗，致使繁殖功能與懷孕率的低落 (Mann *et al*., 1995; Mann *et al*., 2001)。從營養狀態來看，研究報告也指出，由於熱緊迫會導致泌乳牛乾物質採食量降低，這種長時間的能量負平衡現象，會致使牛隻血液中胰島素、類胰島素生長因子-I (insulin-like growth factor-I, IGF-I) 與葡萄糖濃度降低，造成濾泡發育不良、發情表現不明與卵子的品質低落，也會間接的影響了牛隻的繁殖性能 (Ronchi *et al*., 2001)。同樣的，熱緊迫造成公牛陰囊與睪丸的過熱，導致不成熟與畸形精子比例的增加，因而影響受精能力 (Hansen, 1997)。

1.5 改善牛舍降溫紓解牛隻熱緊迫之策略

熱緊迫造成乳牛產業嚴重的經濟損失，這些損失包括降低採食量 (West, 1994)、增重、乳量及繁殖效率等 (Hansen *et al*., 2001)，更嚴重時可導致死亡。以美國為例，熱緊迫造成畜產業一年的經濟損失達 16.9 到 23.6 億美元，其中酪農產業約佔一半，損失達 8.8 到 15 億美元，因此需要投入更多的研究與資金來研發有效的熱緊迫紓解對策 (St-Pierre *et al*., 2003)。

Beede and Collier (1986) 建議自牛舍環境改善、耐熱品種選拔及營養管理三方面來減緩乳牛熱緊迫，其中以牛舍環境改善是最有效與直接的方法。本研究致力於探討牛舍環境改善的方法，對於育種與營養方面則未涉獵。

1.5.1 遮蔭 (shades)

遮蔭可保護乳牛減少來自太陽的輻射熱，被認為是防止熱緊迫最根本的需求。據估計，設計良好的遮蔭可減少乳牛總熱負荷 30%至 50%，遮蔭較無遮蔭可降低乳牛直腸溫度 0.5℃ (38.9 *vs.* 39.4℃) 與減少每分鐘 28 次的呼吸次數 (54 *vs.* 82 呼吸次數/分)，並可增加 10%乳量 (Collier *et al*., 2006)。研究指出，每一頭成年乳牛須要有 3.5 至 4.5 m^2 的遮蔭 (Wiersma, 1982)，且遮蔭屋頂的高度必須至少有 3.5 - 4.5 m 高度，始能有效防止由屋頂反射的太陽輻射熱 (Armstrong, 1994)。雖然

遮蔭可以減少太陽照射的輻射熱，但對於空氣溫度與相對濕度並無降低的效果，因此泌乳牛在濕熱環境下，除了須提供更大面積的遮蔭外 (4.2 至 5.6 m^2)，仍須提供其他降溫方法來紓解熱緊迫 (Buffington *et al*., 1983)。

1.5.2 噴水與吹風 (sprinkler and fan cooling systems)

噴水與吹風是一種普遍用來減少熱緊迫的方法，利用噴水淋濕牛隻表皮，再以風扇吹風加速表皮上水的蒸發來達到蒸發散熱的目的。以同一原理進行降溫的還有水滴很細的噴霧系統 (fog or mist system)，但此一系統不被建議用在濕度高的環境，因為微細的水滴在高濕度下會產生蒸氣浴 (steam bath) 的效應，而取代了冷卻的效果 (Bucklin *et al*., 1991)。

Hillman *et al*. (2001) 以每秒鐘 0.2, 0.9, 或 2.2 m 風速搭配不噴水、每 40 min 噴水或每 20 min 的噴水頻度，探討對牛隻體表蒸發散熱的影響，結果指出單獨增加風速即可以明顯增加體表熱的排除，體表熱排除量自單獨每秒 0.2 m 風速處理的 100 watts/m^2，增加到 2.2 m/s 風速的 480 watts/m^2，增加 4.8 倍；增加風速再與噴水處理配合，更顯著提高體表熱的排除效率，每秒 0.2 m 風速下每 20 分鐘噴水一次的處理的體表熱排除量，增加為 440 watts/m^2，增加噴水處理增加 4.4 倍排熱效率；每 20 分鐘噴水一次的處理下再增快風速到 2.2 m/s，體表熱排除量增加為 900 watts/m^2，又較低風速時增加 2 倍的排熱效率 (圖 1.7)。噴水及吹風是有效並且最經濟的牛隻降溫措施 (Hillman *et al*., 2005)。

在 Florida (Strickland *et al*., 1989), Missouri (Igono *et al*., 1987), 與 Kentucky (Turner *et al*., 1992) 進行噴水吹風降溫方式的田間試驗，設定噴水啟動溫度為 25ºC，噴水時間為 1 - 3 min，然後停止 4.5 - 15 min，風扇在系統啟動時維持運轉。這種降溫方式可以增加飼糧採食量 7.8%，提高產乳量 2.5 kg/day，降低體溫 0.2 - 0.5ºC 及減少呼吸速度 29 %。Chastain and Turner (1994) 推薦在乾燥環境下，將牛隻毛髮吹乾之風速須要達到每秒 2.04 m，但在潮濕的氣候環境下，風速須要增加到每秒 2.9 - 4.0 m 才足夠。另外，由於噴水與吹風的降溫方式須使用大量的水，必須注意水的衛生清潔，以避免疾病的傳播 (Turner *et al*., 1992)。

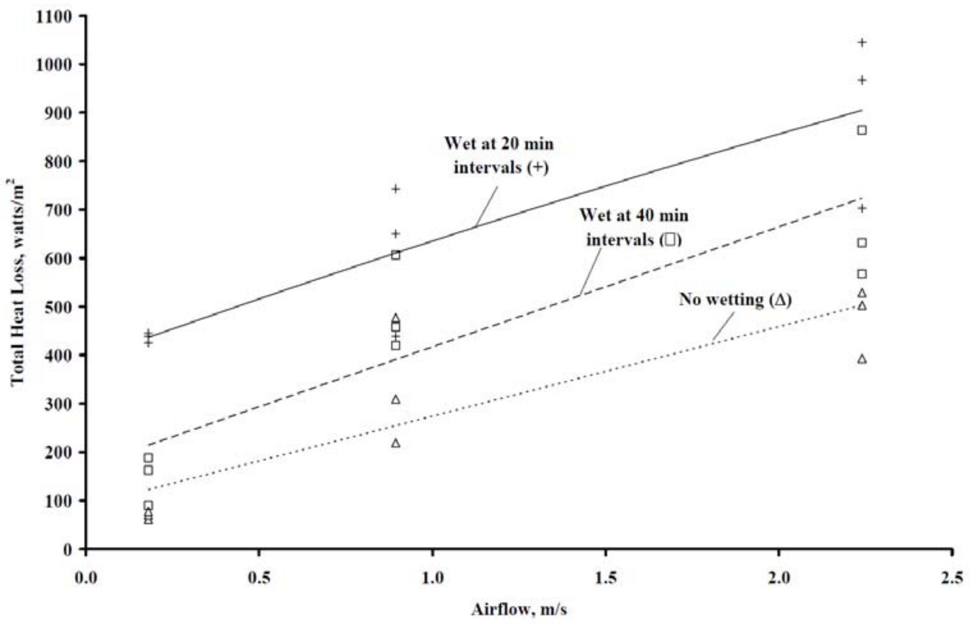

圖 1.7　噴水頻度及風速對體表散熱之影響 (Hillman *et al*., 2001)。

Figure 1.7　Total heat loss from the sample skin for different levels of wetting and airflow (Hillman *et al*., 2001).

1.5.3 隧道式抽風 (tunnel ventilation)

隧道式抽風系統的設計是在一密閉畜舍，一端裝置足夠數量的抽風扇，將空氣自另一端抽入畜舍內，其主要是藉由迅速的將包圍在動物身體週圍的熱與濕度帶走排除，來增加經由對流 (convection) 的熱散失，因此使用隧道式抽風系統的牛舍，會比使用自然通風系統牛舍，有較低的舍內溫度，並減少牛隻一日中曝露於熱緊迫的時間；但較高的耗電量是其缺點 (Stowell *et al*., 2001)。

隧道式抽風系統設計成功與否，取決於牛隻周遭的風速 (air speed at cow level) 與空氣交換速度 (air exchange rate) 是否足夠。Shearer *et al*. (1991) 建議，牛隻周遭的風速要達到每秒 2.5 - 3 m (500 - 600 fpm, feet per min)，才足以提供牛隻冷卻的效果；同時田間試驗結果顯示，在熱的環境下，每頭牛須要的空氣交換速度為每秒 0.5 m^3 (1,000 cfm, cubic feet per min)。另外，在設計牛舍時須考慮是否有足夠的進氣面積來配合最大的抽氣量，以免因進氣不足造成風扇過負荷而降低效率，研究報告建議為配合每秒 0.19 m^3 的風扇抽氣量，至少須要有 930 cm^2 (1 ft^2) 的進氣面積 (Gooch and Timmons, 2000)。

1.5.4 隧道式抽風與蒸發冷卻 (evaporative cooling system)

在隧道式抽風畜舍的進氣端裝置水簾，當空氣被抽入時經過水簾上的流水而降溫，這種畜舍簡稱為水簾畜舍 (tunnel-ventilated water-padded barn)，在豬與雞的降溫飼養上已非常成功的運用，近年來也運用在乳牛舍方面。高溫下，牛以排汗與喘息為主要排熱的方式，因此牛在低相對濕度下較能耐受高溫，在高相對濕度時則不利體熱的排除 (Hillman *et al*., 2001)，蒸發降溫隧道式牛舍造成高的相對濕度，因此一直被認為不適宜用來紓解高濕環境的乳牛熱緊迫，東非與東南非的研究指出，蒸發降溫紓解牛隻熱緊迫的方法適用於乾燥地區 (Bengtsson and Whitaker, 1988)。然而，近年來電子科技與環控技術的進步，全球暖化與氣候大幅度變遷，加上連續熱浪襲擊美國造成牛群大量的損失，蒸發降溫隧道式牛舍再度成為研究的對象。美國東南的 Mississippi 州的夏季較為濕熱，Smith *et al*. (2006a,b) 比較隧道式蒸發散熱與蔭棚+風扇+噴水兩種降溫系統對泌乳牛之影響，結果顯示隧道式蒸發散熱牛舍可以有效減少84%牛隻曝露於中度熱緊迫 (80 < THI < 90) 的時間，降低 3.1 - 5.2℃ 舍溫、每分鐘呼吸次數減少 13 – 16 次、直腸溫度降低 0.4 - 0.6℃, 增加牛隻乾物採食量 11 - 12%, 增加泌乳量 2.6 - 2.8 kg 及降低生乳體細胞數 27 - 49%，顯示在較潮濕的地區仍可以妥善應用水簾牛舍來降溫，其具有明顯實際的正面效果，Berman (2006) 也認為蒸發降溫紓解動物熱緊迫系統在濕的環境下是可行的。

Smith *et al*. (2006a) 指出，利用蒸發降溫系統紓解動物熱緊迫時，其高濕度問題可經由高的風速帶走動物體表熱而得到紓解，因此足夠的風速是水簾牛舍的關鍵之一。Hillman *et al*. (2005) 強調噴水吹風是最經濟的牛隻降溫措施，美國與泰國合作研究也建議，在水簾牛舍中再加入噴水處理，可以有效的降低牛隻呼吸數、皮膚溫度與陰道溫度 (Armstrong *et al*., 2004; Smith *et al*., 2005)，這樣的系統結合了隧道式抽風、水簾降溫入氣、直接牛體噴水降溫與足夠的風速等多項策略優勢，值得再進一步探討。

1.5.5 冷氣 (air condition)

利用冷氣紓解乳牛熱緊迫試驗，早在 1960 及 1970 年代即已評估過，以冷氣來進行牛隻降溫是有潛力的，但是整體牛舍建築與設備的維護與使用上過於昂貴，因此並未被推薦使用 (Bray *et al*., 2003)。國內魯等 (1992) 在炎熱季節比較空

調牛舍與一般牛舍對飼養泌乳前期高產牛的效果，得知空調牛舍可降低牛隻分娩後之失重，並縮短分娩後再發情的天數，同時具有提高產乳量與降低生乳體細胞數之效果。蕭等 (1994，未發表資料) 在夏季以待配女牛進行配種效率比較試驗，荷蘭種女牛分別飼養於空調牛舍與一般開放式牛舍，飼養於空調牛舍女牛有較高的懷孕率，國內研究結果也皆因所需電費過高，不符合經濟效益而無法推廣應用。

泌乳牛舍使用冷氣空調，每一頭牛至少須消耗 2,500 J/s (W) 的電能，因此美國農業工程學會推薦空調牛舍僅適用於在高濕熱環境下之高產泌乳牛群 (ASAE Standards, 2008)。Bray *et al*. (2003) 比較空調牛舍與一般牛舍加上噴水吹風的兩個降溫系統，以 THI 值為指標，得到空調牛舍全日時間皆低於 72，相對的，一般牛舍與外界環境的 THI 值幾乎相同，白天 THI 皆高於 75 (圖 1-8)。試驗之空調牛舍長 70 m，寬 25 m，屋簷高 4.5 m，使用 25 Ton (87.9 kw) 之空調系統，設定溫度為 21℃。試驗的 64 日期間，平均每月耗電量為 90,000 kwh，相當於 5,400 美金之花費。該作者認為在濕熱環境下，唯有空調才能使牛舍環境之 THI 值低於 72。

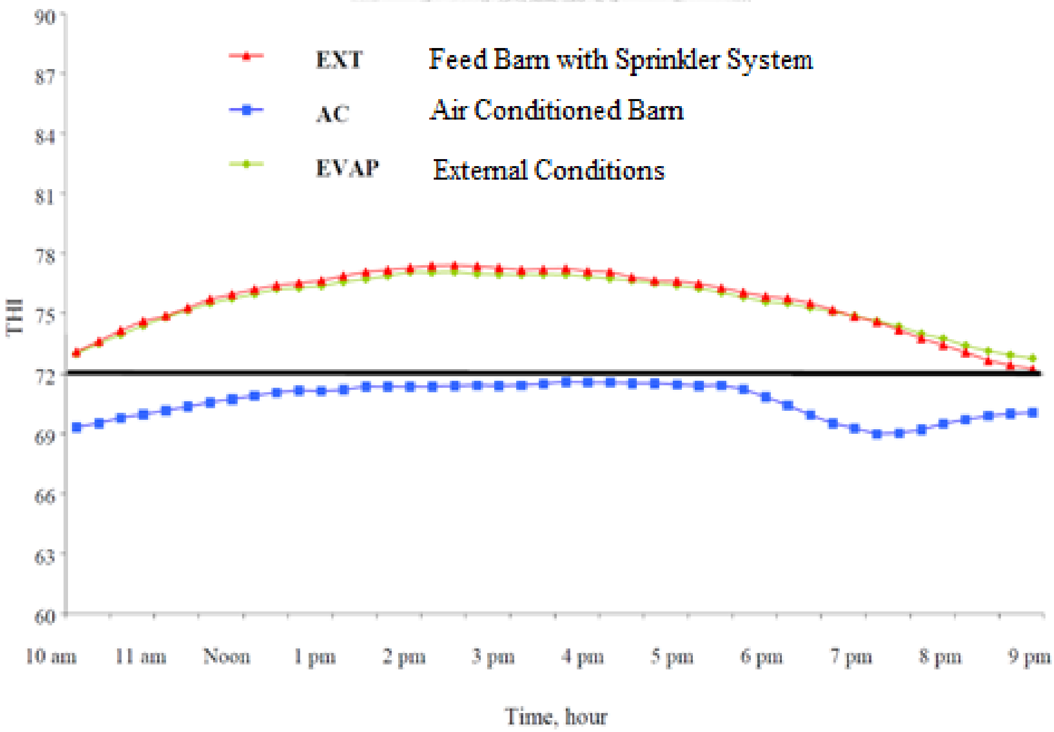

圖 1.8　冷氣降溫牛舍在 64 日試驗期間的平均 THI 變化 (Bray *et al*., 2003)。

Figure 1.8　Average values of the Index of Temperature and Humidity (THI) for 64 days (Bray *et al*., 2003).

另一種變通的空調方式稱為區域冷卻法 (zone cooling)，是將空氣降溫到牛隻舒適帶的溫度，再直接吹向牛隻的頭部與頸部，提供牛隻舒適環境的感覺，因而提高採食量與乳產量。Hahn *et al*. (1965) 利用此方法，將空氣降溫到 15°C，以 0.7 - 0.85 m^3/min 的空氣量吹向牛隻頭部，可以提高產乳量。

1.5.6 其他降溫方式

在 1988 年夏天，美國 Florida 州有約 30% 的乳牛群使用水塘 (pond) 來降溫，由於 Florida 州水資源充沛，人工水塘提供新鮮流動的水源，因此並未提高乳房炎發生比率 (Bray and Shearer, 1988)。直接淋浴 (shower) 是利用傳導與蒸發散熱的方法，提供適度數量的水淋浴 20 s 後，在用約 10 min 吹乾牛隻。通常以定時器控制全場每 90 - 120 min 啟動一次淋浴，若場地過大，則可使用牛隻自動感應器來啟動 (Chiappini *et al*., 1992)。這樣的方式使用水量大，會造成地板溼滑、增加廢水量與泥濘，同時使用的水必需清潔以防止疾病傳染 (Frazzi, 2002)。以色列牛舍多以糞便為乾式墊料，因此加強每日數次牛隻在擠乳等待區的噴水吹風降溫處理，是有效的降溫措施 (Flamenbaum and Ezra, 2007)。屋頂灑水 (water on roof)，是利用水吸收太陽的輻射熱然後蒸發，將熱散發到外面空氣中，如此可以減少太陽輻射熱進入畜舍內 (Nevander and Elmarsson, 1994)。

1.6 台灣的氣候環境

台灣地處亞熱帶，夏季除了高溫問題，嚴重的高濕問題更甚於世界其他很多地區，因此所造成的高溫高濕型熱緊迫一直是台灣乳牛性能表現的瓶頸。自2000年至2009年近10年來，由位於畜產試驗所站號 B2N89 的農業氣象站 (東經120º 26’北緯23º 04’，海拔31 m) 所測得的月平均氣溫與相對溼度及依此計算的溫濕度指數的變化趨勢，繪如圖1.9所示，數據經統計整理，熱季 (5 – 10月) 月平均氣溫、RH與THI，已分別達到27.1℃、84.0%與78.8 (表1.3)。

表1.3 自2000至2009年間畜產試驗所農業氣象站 (B2N89) 所測得的涼熱季氣溫、相對溼度與溫濕度指數

Table 1.3 Daily air temperature, relative humidity and temperature-humidity index at Livestock Research Institute of Taiwan during cool and hot season from 2000 to 2009 (Meterorological Station B2N89)

Season	Air temperature, ℃	Relative humidity, %	temperature-humidity index
Cool (Nov. - April)	20.2 ± 0.5	80.5 ± 2.5	67.2 ± 0.8
Hot (May – Oct.)	27.1 ± 0.2	84.0 ± 1.7	78.8 ± 0.2

同樣的，謝等 (2007) 根據國內中央氣象局 1976 至 2005 年間氣象資料，以每日最高溫度計算 THI (圖1.10)，顯示每年有六個月時間牛隻處於中度熱緊迫 (78 < THI ≤ 84)，2.6 個月處於輕度熱緊迫 (72 < THI ≤ 78)；即使以每日平均溫度計算 THI，每年也有 6.7 個月的氣候環境讓牛隻處於熱緊迫狀況 (THI ≧ 72)，全年只有四個月為最佳人工授精時期 (THI ≤ 68)。陳等 (2009) 根據國內乳牛群性能改良計畫 (Dairy Herd Improvement, DHI) 資料庫挑選台灣北、中及南部地區經營管理良好的酪農戶共六戶，自 2004 年 12 月至 2007 年 11 月為期三年，量測其牛舍內之溫度與相對濕度，並推算其牛舍內之 THI，得到涼季 (12 - 3月)、暖季 (4, 5, 10, 及 11月) 與熱季 (6 - 9月) 時牛舍內 THI 值分別為 66.2, 75.7, 與79.9，表示即使是經營管理良好的酪農戶，全年仍有 2/3 的時間，其牛舍內牛隻仍處於輕度到中度熱緊迫的狀態 (圖1.11)。圖1.12為參試的六戶酪農戶牛舍內與牛舍外各月份 THI 變化，牛舍內在 4 至 11 月間的 THI 值皆高於 72，而 6 至 9 月間的 THI 值更接近於 80。

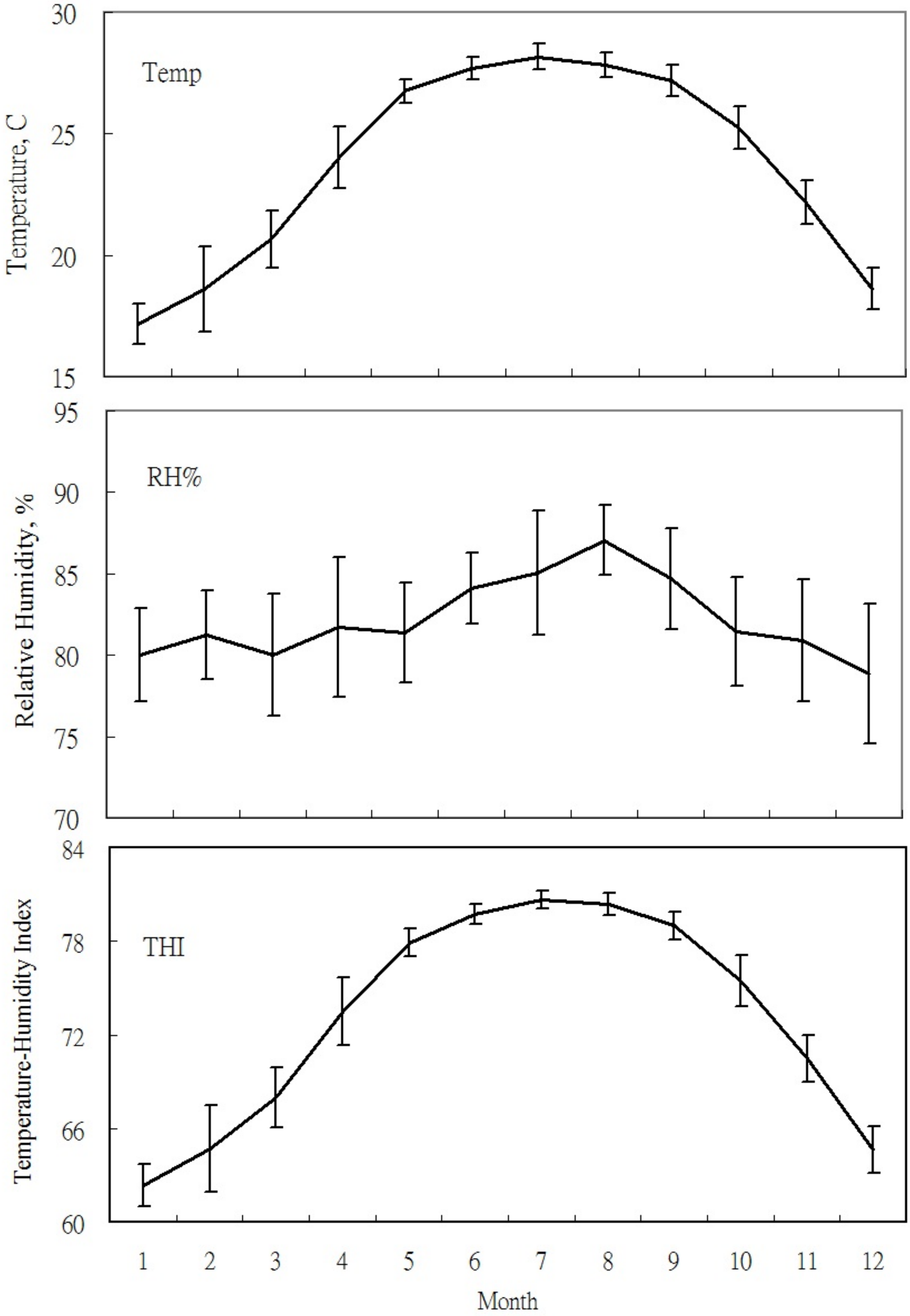

圖 1.9　自 2000 至 2009 年畜產試驗所 B2N89 農業氣象站 (東經 120º 26’北緯 23º 04’，海拔 31 m) 所測得的月平均氣溫、相對溼度與溫濕度指數變化。

Figure 1.9　Monthly averages of air temperature, relative humidity and temperature-humidity index at Livestock Research Institute of Taiwan from 2000 to 2009 (Meterorological Station B2N89).

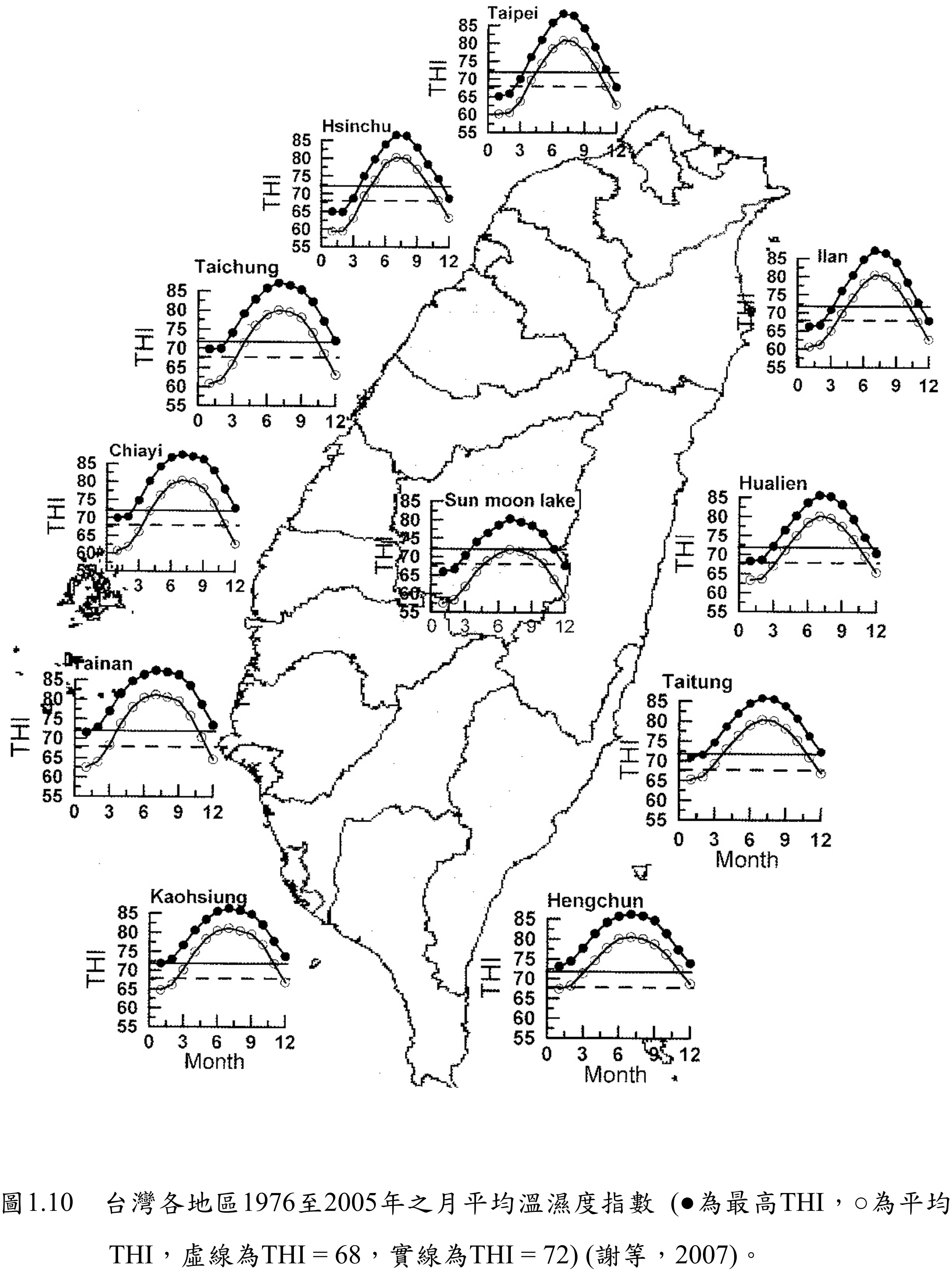

圖1.10　台灣各地區1976至2005年之月平均溫濕度指數 (●為最高THI，○為平均THI，虛線為THI = 68，實線為THI = 72) (謝等，2007)。

Figure 1.10　Monthly averages of temperature-humidity index (THI) from different districts in Taiwan from 1976 to 2005 (● the highest THI, ○ mean THI, dotted line for THI = 68, and solid line for THI = 72).

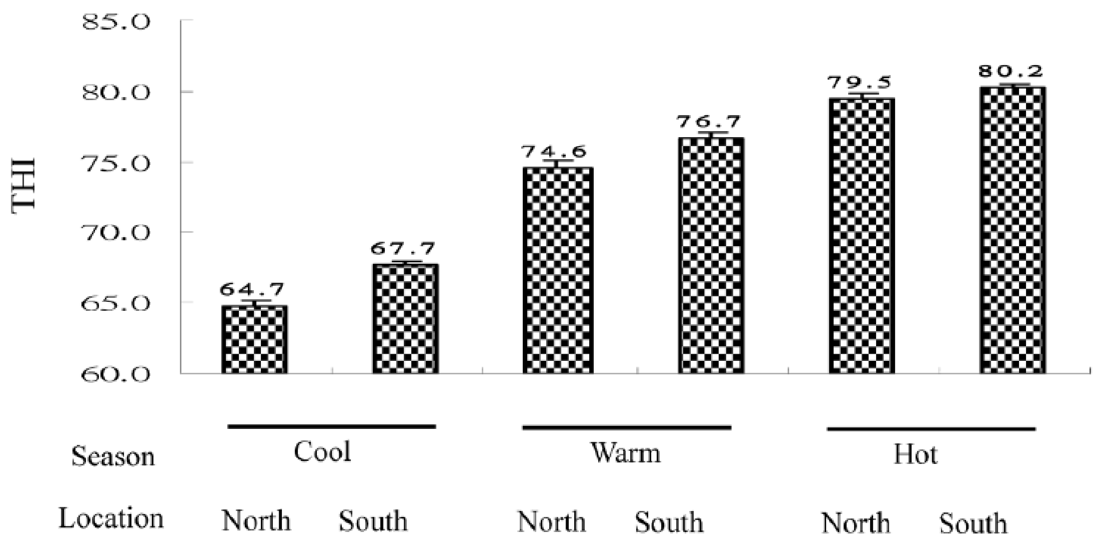

圖1.11　自2005至2007年間參試酪農戶牛舍內於不同季節與地區的溫濕度指數變化 (陳等，2009)。

Figure 1.11　The averaged barn THI at different seasons and areas from six experimental dairy farms from 2005 to 2007 in Taiwan.

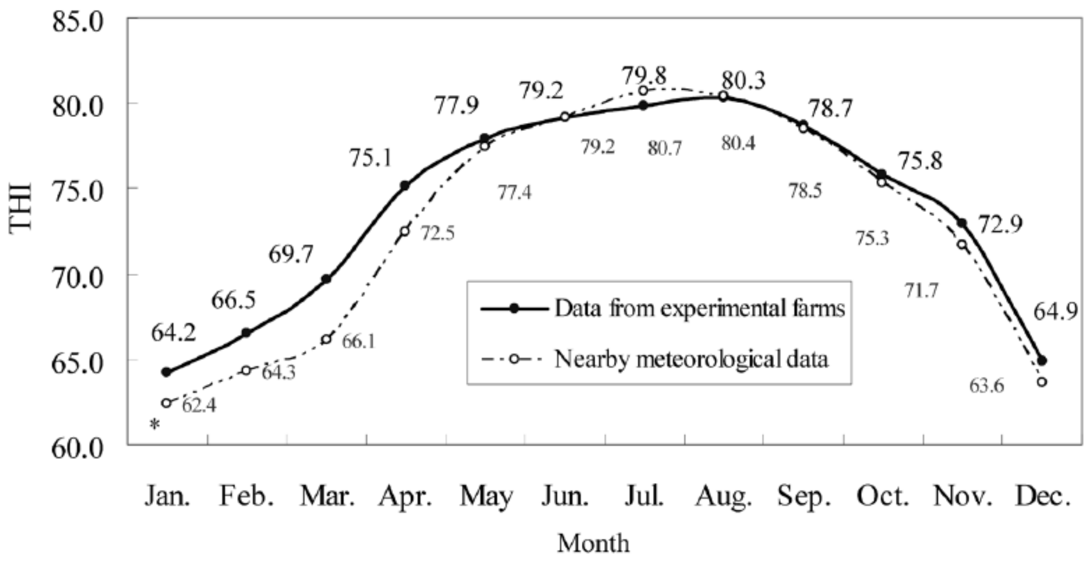

圖1.12　於2005至2007年間參試酪農戶牛舍內與室外各月份溫濕度指數之變化 (陳等，2009)。

Figure 1.12　The monthly changes of barn and outside THI for six experimental dairy farms from 2005 to 2007. Nearby data are collected from four meteorological stands including Taoyang, Yuinlin and Kaohsiung Agricultural Research and Extensions Station and Livestock Research Institute in Tainan.

1.7 試驗緣起與目的

承受熱緊迫的乳牛群，不但須要以排汗與喘氣等方式努力排除體熱外，乳量與繁殖性能都會明顯降低，使夏季酪農業生產效率嚴重受挫，因此如何紓解熱緊迫是國內酪農業發展上的主要瓶頸與挑戰。在國內高濕熱氣候狀況下，提供牛隻蔽蔭的牛舍建築已是必備的設施；李等 (1999) 引入以色列噴水吹風降溫設施，於 1996 年 6 – 9 月間在台灣六個地區的酪農進行試驗，以噴水 1 min 配合吹風 5 min 之方式進行降溫，得知可以有效降低牛隻直腸溫度 0.22℃及每分鐘呼吸數 3.3 次，並且增加乾物質採食量每日 2.03 kg，目前國內酪農於熱季也多採用此種間歇性噴水吹風降溫方法。近年來，在國內經營管理良好的酪農戶進行實地牛舍溫濕度調查，結果全年 2/3 的時間，牛隻仍處於熱緊迫狀況下 (陳等，2009)，顯示紓解熱緊迫這個老問題仍舊存在，有待繼續努力研究。

參考隧道式抽風與蒸發冷卻畜舍 (簡稱水簾舍) 在豬雞產業上的成功應用，同時為斷絕可能的疫病傳播，畜產試驗所於2004年完成一棟密閉式水簾牛舍的建築，自2005年至今持續評估其用於紓解荷蘭泌乳牛熱緊迫的可行性，其間不斷依評估試驗結果進行牛舍局部軟硬體及參數的調整，以期能確實達到紓解牛隻熱緊迫之目標。本次博士論文內容包括2005到2007三年的三個評估試驗報告及2008到2010三年的田間繁殖調查，評估項目包括牛舍環境、牛隻熱生理反應、血液生化值、血中氣體、採食、瘤胃消化、泌乳性能與繁殖性能等。

第二章 以水簾牛舍紓解荷蘭泌乳牛熱緊迫之可行性評估

I. 牛舍環境與牛隻生理反應

2.1 中文摘要

本試驗目的在評估水簾牛舍用於紓解荷蘭泌乳牛熱緊迫的可行性，評估指標為牛舍環境參數與牛隻生理反應。試驗採用交叉設計，42 頭平均乳量 26.2 kg 的荷蘭泌乳牛逢機分成二組，分別飼養於隧道式抽風降溫水簾牛舍 (簡稱水簾牛舍)或傳統的挑高太子樓牛舍 (簡稱傳統牛舍)，兩種牛舍為相同的自由式牛舍，試驗每一期為 30 日，提供牛隻相同的飼養管理。水簾牛舍底端設置整排八臺排氣風扇，對應牆面設置 L 型整面水簾，兩側以厚塑膠捲簾密閉形成隧道，空氣抽入時經過水簾而降溫，再流經牛隻體表帶走體熱；傳統牛舍共懸掛四臺風扇且全日開啟，採食區另設置每日六次每次 30 分鐘的噴水降溫處理。牛隻清晨四點與下午兩點的呼吸數及直腸溫，分別於兩期試驗量測兩天；試驗結束時採取兩天血液樣品測定血清生化值；試驗結束後再補採血樣測定血中氣體分壓等。試驗結果顯示，在最高每分鐘兩次的換氣速度下，水簾牛舍可以較傳統牛舍有效的降低日間最高舍溫 2.4℃、縮短牛隻曝露於 26℃以上熱緊迫的時間 4.5 h，減少牛隻曝露於中度熱緊迫狀況 ($78 < \text{THI} \leq 84$)的時間 2.5 h；然而，水簾牛舍內持續高的相對濕度 (全日相對溼度 ≥93.5%)對牛隻產生不良的影響。水簾牛舍環境下飼養的牛隻在 4 a.m.的呼吸數 (62 *vs.* 50 次/分鐘，$P < 0.001$)、4 a.m.的直腸溫度 (39.58 *vs.* 39.31℃, $P < 0.01$)及 2 p.m.的直腸溫度 (39.75 *vs.* 39.47℃, $P < 0.05$)都顯著高於傳統牛舍牛隻。水簾牛舍牛隻的血清總蛋白質及磷濃度顯著較高；但血清膽固醇及麩胺酸丙酸轉氨酶顯著降低。水簾牛舍環境顯著降低泌乳牛下午餵飼前血液 CO_2 分壓 (41.4 *vs.* 43.8 mmHg, $P < 0.05$)，使血液 pH 值顯著增加。兩種牛舍環境都無法完全紓解泌乳牛熱緊迫，水簾牛舍牛隻的熱負荷更嚴重，推測目前水簾牛舍持續的高濕度狀況及較低的換氣速度，可能影響了牛隻體熱藉由體表蒸散的功能，因此增加水簾牛舍換氣速度應為進一步研究探討的方向。

2.2 緒言

熱緊迫造成乳牛事業嚴重的經濟損失，這些損失包括降低採食量 (West, 1994)、增重、乳量及繁殖效率等 (Hansen *et al.*, 2001)，更嚴重時可導致死亡。以

美國為例，熱緊迫造成畜產業一年的經濟損失達16.9 - 23.6億美元，其中乳牛事業約佔一半，損失達8.8 - 15億美元，因此需要投入更多的研究與資金來研發有效的熱緊迫紓解對策 (St-Pierre *et al*., 2003)。水簾蒸發降溫隧道式畜舍 (水簾畜舍)用於紓解熱緊迫，已廣泛的應用於豬與家禽，且成效良好。高溫下，牛以排汗與喘息為主要排熱的方式，因此牛在低相對濕度下較能耐受高溫，在高相對濕度時則不利體熱的排除 (Hillman *et al*., 2001)，蒸發降溫隧道式牛舍造成高的相對濕度，因此一直認為不適宜用來紓解濕熱環境的乳牛熱緊迫，東非與東南非的研究指出，蒸發降溫紓解牛隻熱緊迫的方法適用於乾燥地區 (Bengtsson and Whitaker, 1988)。然而，近年來電子科技與環控技術的進步，二十年前無法做到的事，以今日的技術或許不成問題，同時全球暖化與氣候大幅度變遷，加上連續熱浪襲擊美國造成牛群大量的損失，蒸發降溫隧道式牛舍再度成為研究的對象。Berman (2006)認為蒸發降溫紓解動物熱緊迫系統在濕的環境下亦可利用，Smith *et al*. (2006a)也指出，水簾牛舍較開放式牛舍可降低3.1 - 5.2℃舍溫、每分鐘呼吸次數減少13 - 16次、直腸溫度降低0.4 - 0.6℃、減少84%牛隻曝露在中等熱緊迫 ($80 < THI < 90$)的時間、增加牛隻乾物採食量11 - 12%、增加泌乳量2.6 - 2.8 kg及降低體細胞數27 - 49% (Smith *et al*., 2006b)。利用蒸發降溫系統紓解動物熱緊迫時，高濕度造成的緊迫可經由高的風速帶走動物體表熱而得到紓解。

乳牛經由瘤胃發酵及代謝過程產生大量的熱，隨著乳量的提高，熱生成也伴隨著增高，為維持體溫的恆定，牛隻必需將過多的熱即時排除。隨著氣溫的增加，牛隻散熱方式自非蒸發 (non-evaporative)的對流 (convection)、傳導 (conduction)與輻射 (radiation)，轉換成蒸發式的流汗 (sweating)與喘氣 (panting) (Kibler and Brody, 1953)。當氣溫達 19℃時牛隻呼吸次數開始增加，氣溫達 25℃時開始排汗 (Hahn *et al*., 1997; Maia *et al*., 2005ab)。高溫環境下，牛隻以流汗為主要散熱方法，但喘氣則比較容易被管理者觀察到，牛隻流汗與喘氣分別完成 85%與 15%的蒸發散熱功能 (Maia *et al*., 2005b; Hillman, 2009)。牛隻排汗速率受到相對濕度與風速的影響，當相對濕度由 30%提高到 90%時，排汗速率由 500 g $H_2O/(m^2h)$ 降低至 60 g $H_2O/(m^2h)$ (Maia *et al*., 2005b)，經過牛隻體表的風速由 0.2 m/s 提高到 0.9 m/s 時，排汗速率由 75 g $H_2O/(m^2h)$ 提高到 350 g $H_2O/(m^2h)$，再提高風速至 2.2 m/s 並不會增加排汗速率 (Hillman *et al*., 2001)。

在熱緊迫的研究上，使用環境或動物表現來評估熱緊迫程度。溫濕度指數

(temperature-humidity index, THI)是常用的環境指標，THI 公式與劃分方法多元，其中多以 Armstrong (1994)為基礎，其定義 THI < 72 時，牛隻感受舒適且無緊迫 (no stress)、72 < THI < 78 表示輕微的熱緊迫 (mild stress)、78 < THI < 89 表示牛隻處於中度緊迫狀況、89 < THI < 99 表示嚴重的熱緊迫 (severe stress)、THI > 99 為致命狀況 (fatal)；Hahn *et al*. (2009)將 THI 合併家畜氣候安全指數 (livestock weather safety index)，劃分 THI ≤ 74、75 – 78、79 – 83 及 ≥ 84 分別代表正常、警告、危險及緊急狀況。在動物表現方面，呼吸速度 (respiration rate)與直腸溫度 (rectal temperature)為良好的熱緊迫指標，氣溫高於中溫帶 (thermoneutral zone)後，牛隻呼吸速度與氣溫成高度正相關 (Hahn *et al*., 1997)。中心體溫 (body core temperature)的量測因量測部位不同而異，包括直腸、耳鼓膜 (ear tympanic membrane)、皮下 (sub-dermal)、瘤胃、陰道及腹腔 (peritoneal cavity)，其中直腸溫最高，鼓膜及腹腔溫度較直腸溫低 0.6℃，且與直腸溫具很高的相關性 (Brown-Brandl *et al*., 2001)。當氣溫高於中溫帶後，牛隻皮下溫度跟隨直腸溫度的變化而變化，但若氣溫等於或低於中溫帶則無此現象 (Hahn *et al*., 1997)，因此在熱緊迫狀況下，利用紅外線溫度計量測牛隻表皮溫度，可與呼吸速度有很高的相關，同時也是量測牛隻周圍微環境很好的方法 (Collier *et al*., 2006)。

牛隻營養代謝也隨熱緊迫程度有所變化，血中尿素氮 (blood urea nitrogen, BUN) 濃度增高，代表飼糧中蛋白質的利用效率降低 (Koubková *et al*., 2002)。乳酸鹽脫氫酶 (lactate dehydrogenase, LDH)是一種葡萄糖代謝過程中的酵素，牛隻血液的正常值推薦為 < 1,500 U/L (Schmid and von Forstner, 1986)。天冬胺酸轉胺酶 (aspartate aminotransferase，AST，即 GOT，glutamic oxaloacetic transaminase)與丙胺酸轉胺酶 (alanine aminotransferase，ALT，即 GPT，glutamic pyruvic transaminase)參與蛋白質代謝過程中胺基的轉換，當牛隻肝臟受損時，血中 AST 與 ALT 活性會升高，但此二轉胺酶的變化並非只對肝臟專一反應 (not liver-specific)。Abeni *et al.* (2007)與 Calamari *et al.* (2007)認為血液生化值可做為快速且可靠的熱緊迫指標，熱季會造成荷蘭牛血漿中葡萄糖 (glucose)濃度的降低，血漿中葡萄糖濃度與一日中最高 THI 值成極顯著的負相關 ($P < 0.001$)；熱季使血漿中膽固醇 (cholesterol)濃度與鹼性磷酸酶 (alkaline phosphatase, ALP)活性顯著降低，二者與 THI 值成直線性的負相關；血漿中肌酸酐 (creatinine)為蛋白質代謝產物之一，也用為肌肉量的指標，熱季血中濃度的升高可能來自肌肉蛋白質的釋出增加 (Fekry *et al*., 1989)，

肌酸酐與牛隻直腸溫成極高的正相關 (P < 0.001)。乳牛長期曝露在高溫環境下會影響其體內的酸鹼平衡 (West *et al*., 1991)，身體經由化學緩衝作用、呼吸調節血中碳酸及腎臟調節對氫離子 (H^+)或重碳酸根離子 (HCO_3^-)的排出等三種機制，來維持正常的酸鹼平衡 (Houpt, 1993)。當熱負荷增加時，牛隻須藉由喘氣來提高上呼吸道的蒸發散熱作用，但喘氣使 CO_2 的排出大於生成，CO_2 的排出增加促使 H^+ 與 HCO_3^- 合成碳酸 (H_2CO_3)，因此喘氣雖有助排熱，但也造成呼吸性鹼毒症 (respiratory alkalosis)現象，即血中 CO_2 分壓降低、HCO_3^- 濃度降低及血液 pH 值上升 (Collier *et al*., 1982; Calamari *et al*., 2007)。

台灣地處亞熱帶海島型氣候，夏季高溫多濕對於荷蘭乳牛造成嚴重熱緊迫現象 (謝等，2007；陳等，2009)，諸如牛隻採食量降低、乳量降低、生長延遲及繁殖效率顯著低落等。本次試驗在於探討在高溫多濕的環境下，利用水簾方式降溫紓解泌乳牛夏季熱緊迫的可行性，評估指標以牛舍環境與牛隻生理反應為主，同期另一份報告則以採食、瘤胃消化與泌乳性能為評估項目 (蕭等，2009ab)。

2.3 材料與方法

本研究涉及之動物試驗於行政院農業委員會畜產試驗所執行，動物之使用、飼養及實驗內容係依據行政院農業委員會畜產試驗所實驗動物管理委員會批准之試驗準則進行。

2.3.1 水簾牛舍

水簾牛舍為隧道式自由牛舍設計，如圖 2.1 所示，座落於台南縣新化鎮行政院農業委員會畜產試驗所，總面積為 50 × 15 m^2，參試牛隻活動面積 21 × 11 m^2，每一牛床面積 1.2 × 2.4 m^2，二排頭對尾式共 52 座牛床。屋頂高度 5.75 m，屋簷高度 3.95 m，天花板高度 2.5 m，屋頂為雙層具散熱透氣孔彩色鋁鋅鋼板。水簾為三層立體蜂巢狀塑膠製成，厚 0.45 m，兩片面積為 7.2 × 1.8 m^2，另一片面積為 5.85 × 1.8 m^2，共三片牆。在水簾的對面牆，設置直徑 48’’、1 Hp、排氣量 32,000 m^3/h 排風扇 8 臺。牛舍內設置 1.5 × 0.5 × 0.5 m^3 之不銹鋼自動水槽 4 座，牛舍內走道設置自動刮糞機，每日除主要採食期間及夜間 10 時至隔日清晨 3 時不刮糞外，每 3 h 刮糞一次。將水簾牛舍由中分成 2 區，每區飼養 24 頭泌乳牛，飼養密度約每頭 9 m^2。

水簾牛舍通風量以 Fancom F-Central 電腦系統 (Fancom Agri-Computers, Panningen, Netherland) 控制，設定當牛舍溫度 < 26℃，最低通風量為 3 座風扇，

以確保最低新鮮之空氣量，通風量隨著室內溫度之上升而增加，設定差距溫度 (offset temperature) 每增加 0.8 ℃時增加 1 座風扇啟動，最高通風量為 7 座風扇，反之每下降 0.8 ℃時減少 1 座風扇啟動，直到最低通風量為止。水簾上水流的啟動原以相對濕度來控制，但由於水簾內相對濕度接近 100%，因此改以溫度來控制，也設定 ＞26℃後啟動水簾。

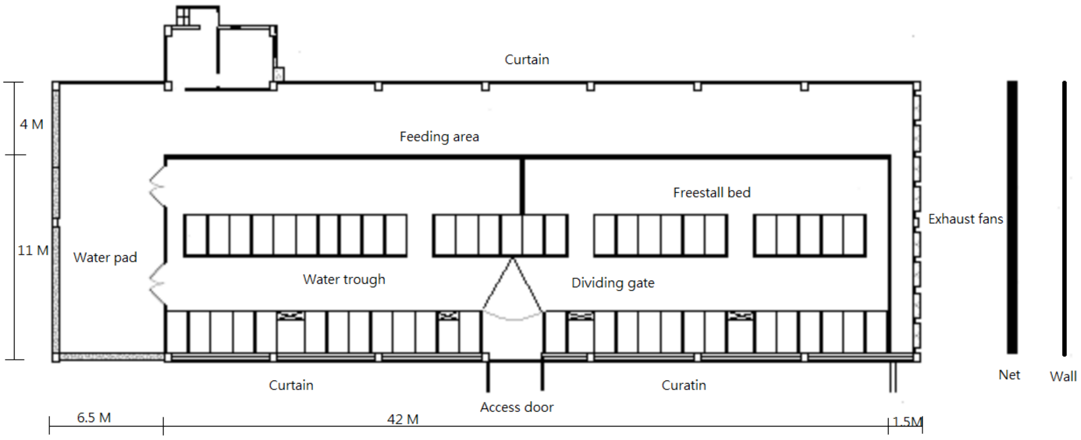

圖 2.1　水簾牛舍平面設計圖。

Figure 2.1　Floor plan of the tunnel-ventilated, water-padded barn.

2.3.2 傳統牛舍 (conventional barn)：

傳統牛舍亦為開放式自由牛舍 (free stall) 設計，與水簾牛舍相鄰，總面積為 $60 \times 30\ m^2$，參試牛隻活動面積 $24 \times 10\ m^2$，每一牛床面積 $1.2 \times 2.4\ m^2$，二排並列式共 28 座牛床。中間屋頂高度 11.8 m，兩側屋簷高度 3.4 m，屋頂為厚度 0.45 mm 彩色鋁鋅鋼板加上隔熱層。牛舍內懸掛 4 臺風扇由人工控制，試驗期間全日開啟，餵飼道及牛床上方各 2 支，風扇之規格為 2.0 Hp，直徑 36’’，3 葉片，排氣量 26,300 m^3/h。於採食區上方設噴水降溫設施，噴水系統於早上餵飼後的 5:30 - 6:00、6:30 - 7:00、10:30 - 11:00、下午餵飼後的 15:50 - 16:20、16:50 - 17:20 及 17:50 - 18:20，一日共六次定時啟動，每次進行連續六次循環，每一循環為噴水一分鐘停止四分鐘，噴水器的水量約每分鐘 2.4 L H_2O。李等 (1999) 引入此種降溫方式，可以有效降低牛隻直腸溫度及呼吸數並且增加採食量，目前酪農於夏季多採用，因此本試驗以此作為對照組。牛舍內設置 $1.5 \times 0.5 \times 0.5\ m^3$ 之不銹鋼自動水槽 2 座，牛舍內走道設置自動刮糞機，每日除採食期間及夜間 10 時至隔日早上 3 時不刮糞外，每 3 h 刮糞一次。

2.3.3 試驗設計

本次試驗以交叉設計 (cross-over design) 為主架構，試驗期間自 2005 年 7 月至 9 月進行，為期 60 天，包括第一期 30 天 (7 月 11 日至 8 月 9 日) 及第二期 30 天 (8 月 10 日至 9 月 8 日)，每期前 15 日為適應期，後 15 日為正式資料收集期。試驗處理為牛舍型式，分別為處理組的水簾牛舍與對照組的傳統牛舍，第一期結束時將兩組牛群移換到另一牛舍中飼養。另因個別原因，在牛隻血液生化值與氣體部分的測定採完全逢機設計 (CRD)。

2.3.4 試驗牛群之飼養管理

2.3.4.1 試驗牛群：選擇乳量 20 kg 以上的荷蘭泌乳牛 42 頭，依照乳量、胎次、泌乳天數與體重等逢機均分為二組，分別群飼於水簾牛舍或傳統牛舍。原始參試 42 頭泌乳牛之平均泌乳天數為 141 ± 60 天 (Mean ± SD，下同)、胎次 2.4 ± 1.4 胎、體重 595 ± 68 kg 及泌乳量 26.2 ± 5.5 kg。

2.3.4.2 牛群管理：泌乳牛每日擠乳兩次，分別為清晨 5:00 與下午 3:15，逐日電腦記錄個別乳量。兩種牛舍設置相同的頸夾餵飼走道、牛床及不銹鋼水槽，糞尿處理採定時刮糞處理。二牛舍皆採滿額飼養，以符合實際狀況。牛群按試驗日程於試驗開始、第一期結束與試驗結束日連續兩日過磅，並按月藥浴。

2.3.4.3 牛群飼養：兩組 TMR 配方相同，配方包括青貯玉米料、盤固乾草、苜蓿乾草、脫水苜蓿粒及精料等，依 NRC (2001) 乳牛營養需要推薦提供乳量 30 kg 之營養需求，飼糧精料比例 45%，並含有粗蛋白質 16.9% 與中洗纖維 34.5% (乾基)。每日分別於清晨及下午配製兩次，使達任食。

2.3.5 環境資料收集

2.3.5.1 溫濕度之測定：在水簾牛舍吊掛溫濕度測定器 (HOBO Pro RH/Temp, Onset Computer Corporation, Bourne, MA)，位置為將牛舍長度分成 4 等份，分別在牛頸夾及牛床上離地 2 m 高度處各設置一溫濕度測定器，共計 8 個；在傳統牛舍吊掛相同型式溫濕度測定器 3 個，位置為將牛舍長度分成 3 等份，在牛頸夾上離地 2 m 高度處各設置一支測定器；同時在牛舍外牆屋簷下離地 2 m 高度處，安置溫濕度測定器 2 個。設定測定器連續每 0.5 h 測定溫濕度乙次，每週讀取資料一次，將各

牛舍及舍外數據分別平均，統計每日平均溫度及相對濕度、記錄最高與最低數值，並依下述公式計算 THI。

2.3.5.2 THI 之計算公式：

$$THI = 9/5 \times T + 32 - 0.55 \times (1 - RH) \times (9/5 \times T - 26)$$

式中 T = 溫度，℃

RH = 相對濕度 (relative humidity)，以小數點方式表示 (NOAA, 1976)

2.3.5.3 熱緊迫程度之定義：因牛隻泌乳性能的持續改進，對體熱生成的敏感度也愈高，本次研究採用 $THI \le 72$, $72 < THI \le 78$, $78 < THI \le 84$, 及 $THI > 84$ 的區分方式來表示舒適、輕度熱緊迫、中度熱緊迫與嚴重熱緊迫。

2.3.6 牛隻熱緊迫生理反應測定項目

2.3.6.1 呼吸次數與直腸溫度：每期正式資料收集期間，重複兩天於清晨 4 點與下午 2 點，測定兩組 11 頭高產牛的呼吸次數與直腸溫度，試驗開始時傳統牛舍組與水簾牛舍組的高產牛平均乳量分別為 30.0 ± 3.9 kg 與 29.7 ± 4.6 kg。呼吸次數測定由三位工作人員執行，在保持安靜不干擾牛隻狀況下，每人以碼錶量測 2 次牛隻 30 秒中腹部起伏次數，三人平均所得為個別牛呼吸次數。直腸溫度以 5 支經同步校正之軟式溫度探針，藉由導管置入牛隻直腸內 30 cm 處 30 秒鐘後，以數字溫度計 (YSI scientific division digital-thermometer, 49TA, Fisher Scientific Co., Pittsburgh, PA) 讀取體溫數值。

2.3.6.2 血液生化值：為避免因採血影響試驗數據收集，於全期試驗結束當日下午 2:00，分別自二處理組牛隻尾靜脈採集血樣，不加抗凝劑，血樣經靜置 1 h 後以 3,000 rpm 及 15 min 離心分離血清，所得血清以血液自動分析儀 (Data Pro Plus random access clinical analyzer, ThermoTrace, Victoria, Australia) 分析血清中白蛋白 (albumin, Alb)、總蛋白 (total protein, TP)、鈣、磷、葡萄糖、膽固醇、BUN, AST, ALT, ALP, 肌酸激酶 (creatine kinase, CK) 與 LDH。

2.3.6.3 血液氣體：由於血液氣體測定儀的維修與特殊採血針的購買，試驗期間雖有採集血液進行氣體分析，但未能完成，因此於 2005 年 11 月 9 日下午 2:00，再選取已在傳統牛舍 (No. = 10) 與水簾牛舍 (No. = 20) 滿額飼養一個月以上的泌乳牛，自頸靜脈以血液氣體採血針 (Blood Gas Monovette®, SARSTEDT Inc., Newton, NC)採集血液，隨即置入冰槽中，於 2 h 內以血液氣體測定儀 (pH/Blood Gas

Analyzer, Instrumentation Laboratory, Model 16200-06, Milan, Italy) 分析血液 pH、氧分壓 (pO_2)、二氧化碳分壓 (pCO_2) 及 HCO_3^-。

2.3.7 統計分析

本次試驗所收集之資料，以統計分析系統套裝軟體 SAS (2003) 進行一般線性模式 (general linear model, GLM) 分析，比較畜舍處理效應。呼吸次數與直腸溫度採用交叉設計統計模式分析；血液生化值與血液 pH、氧及二氧化碳分壓等，採用完全逢機設計 (CRD) 統計模式分析。試驗差異顯著水準設定為 $P < 0.05$，P 值約在 0.10 時，也列出以顯示明顯趨勢。

2.4 結果與討論

2.4.1 環境氣候

試驗於 2005 年夏季執行，試驗 60 天期間每日每 0.5 h 的大氣、傳統牛舍及水簾牛舍之溫度、RH 及 THI 之變化，如圖 2.2 所示，圖 2.3 顯示三種環境內各氣候區分的累積比例。由圖 2.2 (a) 顯示，平均一日中高於 30℃之時間，大氣長達 8 h，傳統牛舍也有 5.5 h，而水簾牛舍則未高過 30℃，大氣、傳統牛舍與水簾牛舍的一日最高溫分別為 32.9℃、31.1℃及 28.7℃，水簾牛舍最高溫發生在下午 1 點，較大氣降低 4.2℃，較傳統牛舍降低 2.4℃，降低幅度較低於 Smith *et al.* (2006a) 蒸發散熱隧道式牛舍可有效降低畜舍最高溫度 3.1 及 5.2℃。如以乳牛最高臨界溫度 25 到 26℃為依據 (Berman *et al.*, 1985)，由圖 2.3 (a) 看來台灣南部地區 7 - 9 月間的大氣溫度，每日超過 26℃的時間長達 20 h，傳統牛舍可減少 2.5 h 牛隻曝露於 26℃以上的時間，水簾牛舍則可減少 7 h 牛隻曝露於 26℃以上的時間。由環境溫度的測定結果看來，水簾牛舍是可以有效的縮短牛隻日間曝露於熱緊迫的時間。

由圖 2.2 (b)中可知，大氣、傳統牛舍及水簾牛舍一日中相對濕度最低的時間在下午 1 點時段，也是一日中溫度最高的時候。傳統牛舍之相對濕度隨著大氣相對濕度變化，形成兩條相平行的曲線，傳統牛舍相對濕度約高於大氣相對濕度 6%到 7%；水簾牛舍為了降低室內溫度啟動水簾，藉由水蒸發散熱的原理來降低畜舍內溫度，相對的也提高了畜舍內的相對濕度，造成全日牛舍內相對濕度皆高於 93.5%以上。圖 2.3 (b) 顯示試驗期間平均一日中各階段相對濕度之比例，大氣、傳統牛舍及水簾牛舍一日中相對濕度 ＞90%者分別為 33, 56, 及 100%；相對濕度 ＞80%者分別為 60, 75, 及 100%；相對濕度 ＞70%者分別為 77, 100, 及 100%；大氣其餘

23%的相對濕度介於 60 到 70%。

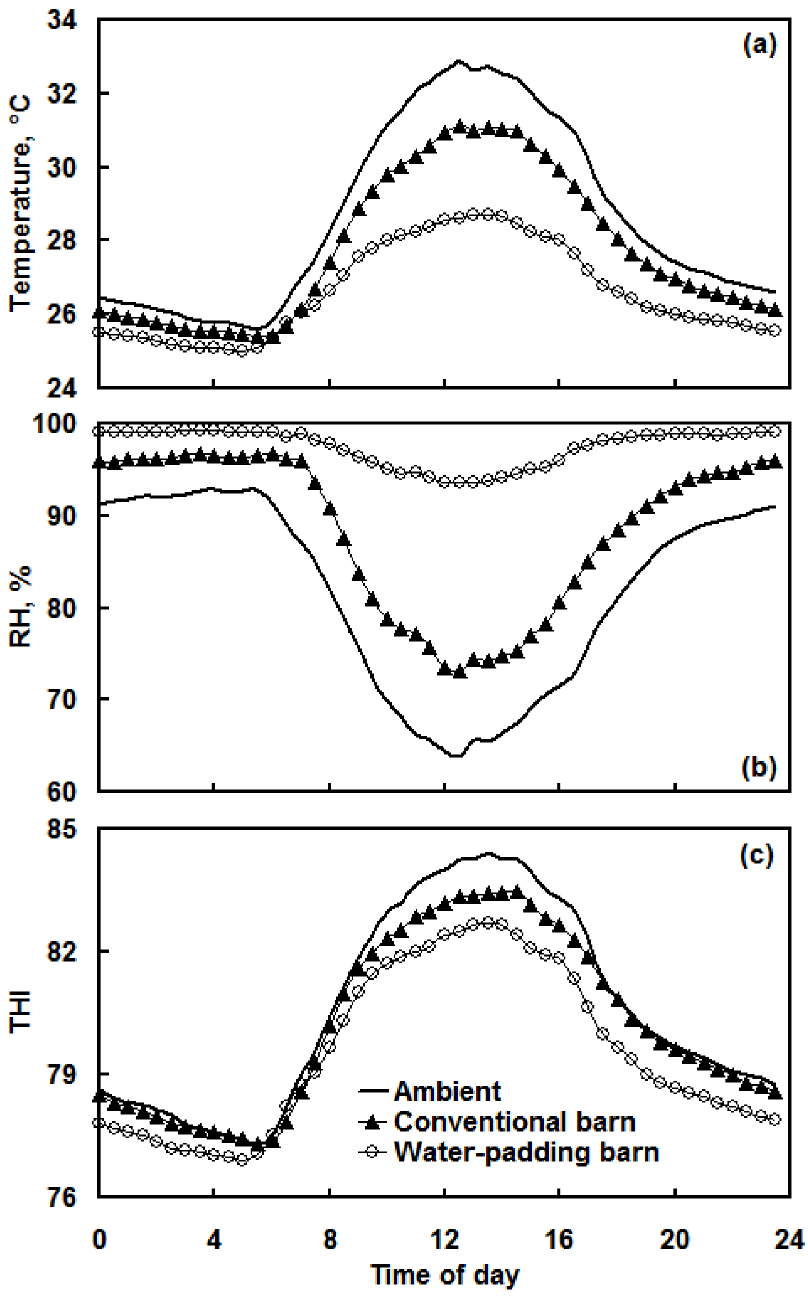

圖 2.2　2005 年夏季水簾牛舍評估試驗期間大氣、傳統牛舍及水簾牛舍一日中溫度、相對濕度與 THI 的變化。

Figure 2.2　Averaged diurnal changes of the temperature (a), relative humidity (RH) (b), and temperature-humidity index (THI) (c) of the ambient, water-padding barn, and conventional barn from the 11^{th} of July to the 8^{th} of Sept. in 2005.

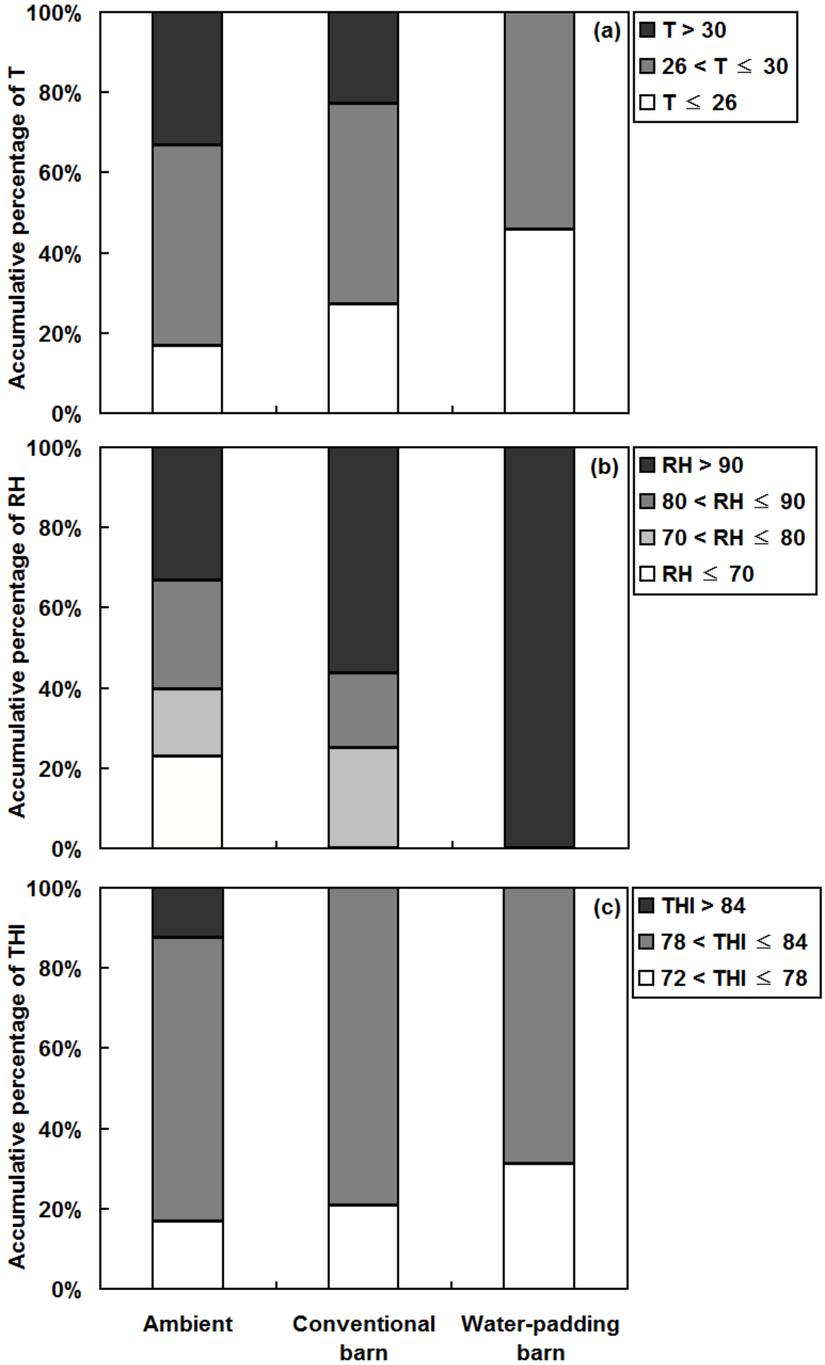

圖 2.3　2005 年夏季水簾牛舍評估試驗期間大氣、傳統牛舍及水簾牛舍一日中溫度、相對濕度與 THI 各區段的累積變化。

Figure 2.3　Accumulative percentages of individual segments of diurnal temperature (T) (a), relative humidity (RH) (b), and temperature-humidity index (THI) (c) in the ambient, conventional barn, and water-padding barn from the 10^{th} of July to the 8^{th} of Sept. in 2005.

圖 2.2 (c) 及圖 2.3 (c) 顯示試驗期間平均一日內 THI 值之變化與分佈。試驗期間，台南地區大氣的 THI 值僅有清晨 3:00 到 6:00 間的 3 h，處於輕度熱緊迫狀況 (72 < THI ≤ 78)，其餘大部分時間大氣的 THI 值都處於中度熱緊迫狀況下 (78 < THI ≤ 84)，甚至於 12:00 至 14:30 間的 2.5 h，THI 值為高於 84 的嚴重熱緊迫狀況；傳統牛舍的 THI 值僅有清晨 2:00 到 6:30 間的 4.5 h，處於輕度熱緊迫狀況，其餘的 19.5 h 之 THI 值都處於中度緊迫狀況下；而水簾牛舍的 THI 值在半夜 23:00 到翌日清晨 6:00 間的 7 h，處於輕度熱緊迫狀況，其餘 17 h 之 THI 值處於中度緊迫狀況下。由此看出，水簾牛舍較傳統牛舍可以減少牛隻曝露於中度緊迫狀況達 2.5 h，此與 Smith *et al*. (2006a) 所述水簾牛舍可以降低牛隻曝露於中度緊迫 (80 < THI < 90) 狀況的結論一致。

圖 2.4 顯示試驗期間每日平均 THI 之變化。所有日平均 THI 值均大於牛隻舒適狀況的 72；不論傳統及水簾牛舍，在熱季時，除了 8 月 14 日至 8 月 19 日間因珊瑚 (Sanvu) 颱風來襲，日平均 THI 稍許得低於 78 外，其餘天數 THI 值均介於中度熱緊迫的 78 至 84 範圍，此對於荷蘭泌乳牛之採食與泌乳性能應造成相當不利的影響。

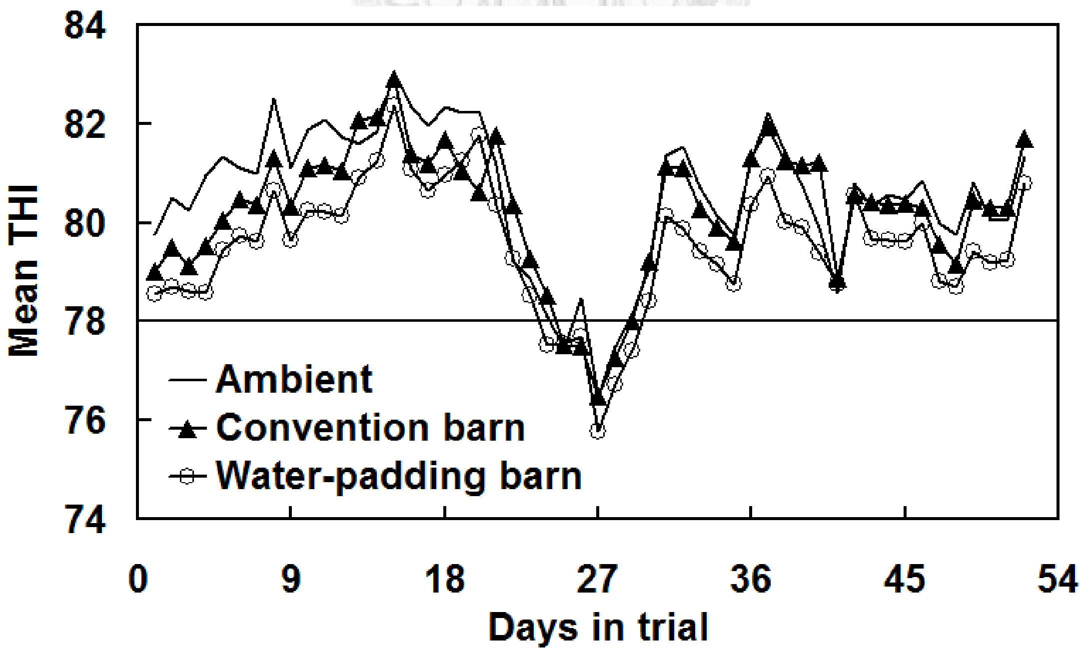

圖 2.4 2005 年夏季水簾牛舍評估試驗期間 (7 月 19 日至 9 月 8 日) 大氣、傳統牛舍及水簾牛舍日平均 THI 變化。

Figure 2.4 Daily temperature-humidity index (THI) changes of the ambient, conventional barn and water-padded barn from the 19th of July to the 8th of Sept. in 2005.

2.4.2 泌乳牛生理反應

2.4.2.1 呼吸次數與直腸溫度

水簾牛舍飼養環境對夏季荷蘭高產泌乳牛呼吸次數與直腸溫度之影響，詳如表 2.1 所示。清晨 4 點時的水簾牛舍牛隻的呼吸次數即已顯著的較傳統牛舍組牛隻為高，分別為每分鐘 62 次與 50 次 ($P < 0.001$)，到下午 2 點時的兩組牛隻呼吸次數更高且相近，分別為每分鐘 71 次與 72 次；以清晨 4 點為基礎值，兩組牛隻下午 2 點的呼吸次數較清晨時分別增加 9 次與 23 次。牛隻在舒適沒有熱緊迫環境下的呼吸次數推薦為每分鐘 26 次到 35 次 (Reece, 1993)，本次試驗測定結果都顯著高於舒適牛隻的表現，甚至在清晨最涼爽時段的呼吸次數都已高達 62 次 (水簾牛舍，約 2 倍呼吸速度)及 50 次 (傳統牛舍，約 1.6 倍呼吸速度)，到下午最熱時段，更高達 71 次 (二牛舍，約 2.3 倍呼吸速度)。水簾牛舍環境下飼養的牛隻清晨 4 點的直腸溫 (39.58℃ *vs.* 39.31℃, $P < 0.01$) 及下午 2 點直腸溫 (39.75℃ *vs.* 39.47℃, $P < 0.05$)都顯著高於傳統牛舍牛隻，兩組牛隻清晨到下午直腸溫度的增加趨勢呈現平行，約為 0.17℃。Andersson and Jonasson (1993) 指出，牛隻在舒適沒有熱緊迫環境下的直腸溫度為 38.0℃到 39.3℃，而本次試驗測定結果顯示，除了清晨 4 點最涼爽時段的傳統牛舍牛隻直腸溫度與推薦的上限相近外，其餘時段不論是在水簾牛舍或傳統牛舍，牛隻直腸溫度都顯著高於舒適牛隻的表現，到下午 2 點最熱時段，二處理組牛隻直腸溫度皆高於推薦上限 39.3℃甚多。

由呼吸次數與直腸溫的測定結果，說明兩種牛舍環境都未能有效的完全的紓解牛隻熱緊迫，而且水簾牛舍環境熱緊迫問題更大，尤其在夜間，此與 Smith *et al*. (2006a) 指出水簾牛舍可有效的減少牛隻每分鐘呼吸次數 15.5 次且降低直腸溫度 0.6℃的結果相左；但 Brouk *et al*. (2001) 的試驗結果顯示，蒸發散熱系統牛舍雖然可降低牛舍溫度，同時也增加了牛舍的相對濕度，因此導致牛隻呼吸次數的增加，該研究人員推測可能是由於高的相對濕度致使牛隻無法利用蒸發散熱來排除體熱的積聚，因此若能加快換氣速度來帶走體熱或許為可行的方式，Brouk *et al*. (2001) 的試驗觀察結果與推論與本次試驗十分相近。

如 Maia *et al*. (2005a, b) 及 Hillman *et al*. (2001) 的研究顯示，相對濕度與風速會影響牛隻排汗效率。導致水簾牛舍組牛隻在直腸溫度與呼吸數皆無法改善的原因，可能為試驗期間水簾牛舍大部分的白日時間為啟動七台抽風扇，測定風速為 1.66 m/s，但夜間溫度低於 26℃時，則以三臺風扇啟動來維持空氣流通與品質，估

算風速僅 0.71 m/s。全程試驗期間皆處於高溫狀況，牛隻蒸發散熱其中的 85% 須經由排汗來完成，但排汗速率受到環境中 90% 以上相對濕度的影響，加上水簾牛舍夜間經過牛隻體表的風速只有 0.7 m/s，兩者不利的環境因素使牛隻體內積聚的熱無法順利排除，熱負荷增加因此促使牛隻須藉由喘氣來提高上呼吸道的蒸發散熱作用。這個現象說明牛隻熱緊迫受多重因素影響，THI 由環境溫濕度計算而來，因此單獨由 THI 來判定牛隻熱緊迫程度並不甚適宜，夜間水簾牛舍 THI 值較傳統牛舍低但卻有較高的呼吸次數的矛盾現象即為一例。

表 2.1 水簾牛舍環境對夏季荷蘭高產泌乳牛呼吸次數與直腸溫度之影響

Table 2.1 Respiration rate (RR) and rectal temperature (RT) of high producing Holstein cows housed in the conventional barn or water-padded barn during hot summer in 2005

Measurements	Conventional barn	Water-padding barn	SEM[1]	Sig.[2]
No. of cows measured	22	22		
Respiration rate (RR), breaths/min				
4 a.m.	50	62	1.3	***
2 p.m.	72	71	1.2	NS
p.m. RR increases	22	9	1.2	***
Rrectal temperature (RT) , ℃				
4 a.m.	39.31	39.58	0.07	**
2 p.m.	39.47	39.75	0.08	*
p.m. RT increases	0.16	0.17	0.09	NS

[1] SEM: standard error of the mean.

[2] Significant level: * P < 0.05, ** P < 0.01, *** P < 0.001, NS: non significant, P > 0.05.

2.4.2.2 血液生化值及氣體

水簾牛舍飼養環境對夏季荷蘭泌乳牛血液生化值之影響，詳如表 2.2 所示。本次試驗於下午 2 點採血時，水簾牛舍與傳統牛舍的舍溫分別為 28.7 與 31.0℃。牛隻的血清總蛋白質分別為 98 g/L 與 92 g/L (P < 0.05)，水簾牛舍牛隻顯著高於傳統

牛舍牛隻，但在血清白蛋白與尿素氮則無顯著差異。Abeni *et al.* (2007) 指出，熱緊迫並不會影響牛隻的血清白蛋白、總蛋白質與尿素氮，但 Koubková *et al*. (2002) 以氣候室探討熱緊迫下的營養代謝問題，指出由 18℃低溫進入 32℃高溫會導致血清中總蛋白質與尿素氮濃度的增高，本次試驗結果自氣溫來看，與前述研究結果並不一致。水簾牛舍與傳統牛舍牛隻的血清中鈣離子濃度相近，但血清中磷離子濃度分別為 4.07 mmol/L 與 2.36 mmol/L ($P < 0.05$)，水簾牛舍牛隻顯著較傳統牛舍牛隻來得高，其差異原因有待進一步探討。Abeni *et al*. (2007) 指出，熱季會造成荷蘭牛血漿中葡萄糖及膽固醇濃度與鹼性磷酸酶活性的降低，鹼性磷酸酶主要的生理功能在於催化體內磷酸酯的合成或水解，即磷酸化或去磷酸化作用，因此是體內最重要能量代謝反應之一的關鍵酵素，牛隻遇熱緊迫時會減少採食，而鹼性磷酸酶活性被認為與飼料利用影響因子有關 (Kunkel *et al*., 1953)。本次試驗所得結果顯示，飼養在兩種畜舍內牛隻的血清葡萄糖濃度沒有差異，但水簾牛舍顯著降低牛隻血清膽固醇濃度，水簾牛舍與傳統牛舍牛隻的血清膽固醇濃度分別為 3.63 mmol/L 與 4.43 mmol/L ($P < 0.05$)；同時水簾牛舍牛隻血清中鹼性磷酸酶活性也有很明確的降低趨勢 (36.7 *vs*. 46.1 U/L, $P = 0.09$)。兩種牛舍牛隻的血清 AST (GOT) 與 LDH 活性無顯著差異，且牛隻間變異大，此與 Abeni *et al*. (2007)報告一致。水簾牛舍泌乳牛的血清 ALT (GPT) 活性顯著的較傳統牛舍牛隻為低，分別為 29.9 U/L 與 39.1 U/L ($P < 0.01$)。Koubková *et al*. (2002) 以高產泌乳牛在氣候室中進行試驗，ALT 活性在環境溫度 32℃且提供蒸發降溫時快速下降，與本次試驗結果相似。牛隻熱緊迫下的血液生化值與酵素等變化，似乎都圍繞在熱所引起的採食量降低與養分消化代謝的主題上。

水簾牛舍飼養環境對荷蘭泌乳牛血液酸鹼值與氣體之影響，詳如表 2.3 所示。水簾牛舍與傳統牛舍環境對牛隻血液 O_2 分壓與 HCO_3^- 濃度的影響相近，但水簾牛舍環境顯著降低了泌乳牛下午 2 點的血液的 CO_2 分壓 (41.4 mmHg *vs*. 43.8 mmHg, $P < 0.05$)，並且極顯著的增加了血液 pH 值 (7.43 *vs*. 7.41, $P < 0.01$)，顯示水簾牛舍環境已造成牛隻呼吸性鹼毒症現象，與相關熱緊迫研究結果類似 (Collier *et al*., 1982；Calamari *et al*., 2007)，快速的喘氣是主要導因。

由牛隻直腸溫度與呼吸數的測定結果，顯示水簾牛舍牛隻較傳統牛舍牛隻的熱緊迫問題更嚴重，從水簾牛舍牛隻血清膽固醇濃度、鹼性磷酸酶活性與 ALT 活性的降低及出現呼吸性鹼毒症現象等牛隻生理反應，也支持此論點。

表 2.2　水簾牛舍環境對夏季荷蘭泌乳牛血液生化值之影響

Table 2.2　Serum biochemical metabolites of Holstein lactating cows housed in the conventional barn or water-padded barn or during hot summer in 2005

Metabolites	Conventional barn (SEM[1])	Water padded barn (SEM)	Sig. [2]
No. of cows measured[3]	18	19	
Total protein, g/L	92 (2)	98 (2)	*
Albumin, μmol/L	0.58 (0.01)	0.59 (0.01)	NS
BUN,[4] mmol/L	5.42 (0.24)	5.23 (0.24)	NS
Ca, mmol/L	2.42 (0.05)	2.36 (0.05)	NS
P, mmol/L	2.37 (0.43)	4.07 (0.42)	**
Glucose, mmol/L	2.84 (0.10)	3.02 (0.10)	NS
Cholesterol, mmol/L	4.42 (0.22)	3.63 (0.22)	*
ALP,[4] U/L	46.1 (3.8)	36.7 (3.7)	(P = 0.09)
AST,[4] U/L	145 (14)	162 (13)	NS
ALT,[4] U/L	39.1 (2.1)	29.9 (2.0)	**
LDH,[4] U/L	734 (38)	737 (37)	NS

[1] SEM: standard error of the mean.

[2] Significant level: * $P < 0.05$, ** $P < 0.01$, P value around 0.1 was also listed, NS: non significant, $P > 0.05$.

[3] To decrease the cows' stress from blood sampling, blood samples were taken only once from individual cow in two barns from their coccygeal vein at the end of the cross-over experiment.

[4] BUN: blood urea nitrogen, ALP: alkaline phosphatase, AST: aspartate aminotransferase, ALT: alanine aminotransferase, LDH: lactate dehydrogenase.

表 2.3　水簾牛舍環境對荷蘭泌乳牛血液酸鹼值與氣體分壓之影響

Table 2.3　Blood pH, partial pressure of gases and HCO_3^- of Holstein lactating cows housed in the conventional barn or water-padded barn in 2005

Items	Conventional barn (SEM[1])	Water-padded barn (SEM)	Sig.[2]
No. of cows measured[3]	10	20	
pH	7.41 (0.006)	7.43 (0.005)	**
pCO_2,[4] mmHg	43.8 (0.9)	41.4 (0.6)	*
pO_2,[4] mmHg	30.2 (1.2)	29.6 (0.9)	NS
HCO_3^-, mmol/L	27.8 (0.4)	27.5 (0.3)	NS

[1] SEM: standard error of the mean.

[2] Significant level: * $P < 0.05$, ** $P < 0.01$, NS: non significant, $P > 0.05$.

[3] Due to unsuccessful blood gas analyses, fresh blood samples were re-taken after the experiment at 2 p.m. on Nov. 9, 2005 from jugular vein of cows already raised in two barns for a period of time.

[4] pCO_2: Partial pressure of carbon dioxide; pO_2: Partial pressure of oxygen.

2.5 結論與建議

水簾牛舍是否可以做為紓解乳牛夏季熱緊迫的方法，由泌乳牛生理反應方面評估的結果，顯示目前水簾牛舍對泌乳牛的熱緊迫紓解有負面影響，因此水簾牛舍的設計須要再進一步探討。水簾牛舍全日持續偏高的相對濕度很可能是導致牛隻無法自體表排熱而表現高熱負荷的主要原因，增加風速與換氣速度應是進一步修正水簾牛舍的主要方向。

第三章 以水簾牛舍紓解荷蘭泌乳牛熱緊迫之可行性評估

II. 採食行為、瘤胃消化與泌乳性能

3.1 中文摘要

夏季高溫高濕的熱緊迫一直是泌乳牛性能表現的瓶頸，本次試驗在評估水簾牛舍紓解泌乳牛夏季熱緊迫的可行性。隧道式的水簾牛舍一端由整排風扇抽氣，將空氣自另一端的水簾片外抽入，經過水降溫的濕空氣流經牛隻體表帶走體熱而降溫；對照組為傳統挑高太子樓牛舍，風扇全日開啟，並於餵飼期間啟動噴水系統降溫。試驗以交叉設計進行，42 頭平均乳量 26.2 kg 的乳牛分成兩組，分別飼養於水簾牛舍或傳統牛舍，每期 30 天，兩組牛隻的飼養管理相同。在日間最高每分鐘兩次的換氣速度下，水簾牛舍可以較有效的降低日間舍溫及溫濕度指數，但水簾牛舍飼養環境明顯減低牛隻的採食活動，尤其在下午餵飼後的兩小時內，水簾牛舍牛群只有傳統牛舍牛群 57% 的採食活動 (採食比例分別為 35.7% 與 62.1%，$P < 0.05$)，牛隻乾物質採食量隨之降低 7.6% (17.0 kg *vs.* 18.4 kg)，牛隻 4%乳脂校正乳量隨之降低 10.1% (23.1 kg *vs.* 25.7 kg, $P < 0.001$)，乳蛋白質與乳總固形物濃度也顯著降低，導致牛隻乳脂肪、乳蛋白質、乳糖及總固形物的日產量也都因此顯著降低。逐日乳量變化趨勢在交叉試驗設計下，也確認本次水簾牛舍環境並不利於牛隻乳量表現。兩種牛舍環境對瘤胃 pH、揮發性脂肪酸與氨態氮濃度的影響，並未達到差異顯著水準。試驗結果顯示，本次水簾牛舍環境全日持續高檔的相對濕度 (≥ 93.5%) 與較低的換氣速度，很可能限制了牛隻體表蒸發散熱的能力，牛隻熱負荷增加導致性能表現降低，因此水簾牛舍的設計還須要更進一步的研究與修正。

3.2 緒言

高生產性能畜禽代謝速率快，其產生的熱須要適當的排出以維持體內環境平衡，當熱的產生大於熱的排除就產生熱緊迫；環境因素如氣溫、相對濕度、太陽輻射與風速等相互影響，當使環境有效溫度 (effective temperature) 高於動物的中溫帶 (thermoneutral zone)或舒適帶 (comfort zone) 溫度，就會造成熱緊迫 (Bianca, 1962)。由於龐大的體軀與快速的代謝速度，泌乳牛對熱緊迫非常敏感，尤其是高產牛。牛隻為紓解熱緊迫，以尋求遮蔭、增加飲水與排尿、減少採食、增加排汗

與喘氣等來散熱 (Bucklin *et al*., 1991; Smith *et al*., 2006a)，若仍無法有效排熱，將導致體溫升高、呼吸次數增加、採食量降低、乳量下降與繁殖性能低落等 (Ingraham *et al*., 1975; Fuquay, 1981; Igono and Johnson, 1990; West *et al*., 2003)。每日直腸溫超過 39℃達 16 小時以上，則造成乳量下降，即使短期的熱緊迫，也可以降低 10%到 20%的乳量，而且對高產牛更嚴重 (Igono and Johnson, 1990)。Rodriquez *et al*. (1985) 分析 Florida 農業試驗站 22,972 筆資料後，顯示在每日最高溫在 8℃到 29℃範圍時，牛隻乳量所受影響小，但 > 29℃後，乳量即快速下降；而乳脂肪與乳蛋白濃度則隨每日最高溫 8℃到 37℃增加而下降。

溫濕度指數 (temperature-humidity index, THI) 是常用來表示牛隻熱緊迫程度的指標之一，有數種分級方法，如 Armstrong (1994) 依據 Frank Wiersma (1990, cited in Armstrong, 1994) 資料，將 THI 區分為 < 72, 72 – 78, 78 – 89, 89 – 99, 及 > 99，分別表示牛隻處於舒適、輕度熱緊迫、中度熱緊迫、嚴重熱緊迫及致命狀況；將 THI 合併家畜氣候安全指數 (Livestock Weather Safety Index)，區分 ≤ 74, 75 – 78, 79 – 83, 及 ≥ 84 分別代表正常、警告、危險及緊急狀況 (Hahn *et al*., 2009)，因牛隻泌乳性能的持續改進，對體熱生成的敏感度也愈高，本次研究採用 THI ≤ 72, 72 < THI ≤ 78, 78 < THI ≤ 84, 及 > 84 的區分方式來表示舒適、輕度熱緊迫、中度熱緊迫與嚴重熱緊迫。THI 與乳量及乾物採食量呈負相關，THI 自 68 增加到 78，乳量降低 21%，採食量降低 9.6%；THI 自 69 起，每增加一單位 THI 就會造成 0.41 kg 乳量的下降 (Bouraoui *et al*., 2002)；也有報告指出，乳量受兩日前的平均 THI 影響最大，每單位 THI 增加分別造成荷蘭牛與娟珊牛 0.88 kg 與 0.60 kg 乳量的下降；乾物採食量受兩日前的平均氣溫影響最大，每度氣溫的增加分別造成荷蘭牛與娟珊牛 0.85 kg 與 0.84 kg 採食量的下降 (West *et al*., 2003)。

Beede and Collier (1986) 建議自牛舍環境改善、耐熱品種選拔及營養管理三方面來減緩乳牛熱緊迫，其中牛舍環境改善是最有效與直接的熱緊迫紓解方法。噴水吹風的蒸發散熱是直接濕潤牛隻體表後帶走體熱，另一種蒸發散熱是將入氣經過水而降溫，冷卻的空氣流經牛隻體表再帶走體溫。畜舍入氣經過水簾上的流水而降溫，再配合隧道式抽風方式的畜舍簡稱為水簾畜舍 (water-padding barn)，在豬與雞的降溫飼養上已非常成功的運用，近年來也運用在乳牛舍方面。利用水進行蒸發散熱在相對濕度低的地區效果良好 (Ryan *et al*., 1992)，但因為其會增加舍內相對濕度，因此在濕熱地區的使用上一直有著很深的疑慮，美國東南的 Mississippi

州的夏季較為濕熱，Smith *et al*. (2006a,b) 比較隧道式蒸發散熱與蔭棚+風扇+噴水兩種降溫系統對泌乳牛之影響，顯示隧道式蒸發散熱可以有效減少 84%牛隻曝露於中度熱緊迫 (80 < THI < 90) 的時間，增加牛隻採食量與乳量，同時顯著降低乳中體細胞數，試驗結果顯示隧道式蒸發散熱系統的在美國較濕的地區仍舊可以有正面效果。

臺灣地處亞熱帶，夏季高溫高濕所造成的熱緊迫一直是乳牛性能發揮的瓶頸。謝等 (2007) 根據國內中央氣象局 1971 至 2000 年資料，以每日最高溫度計算 THI，顯示每年有六個月處於中度熱緊迫，2.55 個月處於輕度熱緊迫；即使是經營管理良好的酪農戶，其牛舍內 THI 在涼、暖與熱季分別達到 66.3, 75.7, 與 79.8，表示全年仍有 2/3 的時間，牛舍內牛隻仍處於輕度到中度熱緊迫的狀態 (陳等，2009)。在國內濕熱氣候條件下，提供牛隻蔽蔭的牛舍建築已是必備的設施，李等 (1999) 引入以色列噴水吹風降溫設施，得知可以有效降低牛隻直腸溫度及呼吸數並且增加採食量，目前酪農於夏季也多採用。為更進一步探討紓解乳牛熱緊迫的方法，行政院農業委員會畜產試驗所於民國 93 年完成一棟水簾牛舍的建立，民國 94 年起連續評估其用於紓解國內泌乳牛熱緊迫的可行性。

3.3 材料與方法

本研究涉及之動物試驗於行政院農業委員會畜產試驗所執行，動物之使用、飼養及實驗內容係依據行政院農業委員會畜產試驗所實驗動物管理委員會批准之試驗準則進行。

3.3.1 試驗設計與處理

試驗採二處理的交叉設計 (crossover design)，每期 30 天，每期前 15 天為適應期，後 15 天為正式試驗資料收集期。試驗處理為兩種牛舍型式，包括水簾牛舍處理組與傳統挑高太子樓牛舍配合噴水吹風降溫設施的對照組，簡稱傳統牛舍 (conventional barn)。兩種牛舍都是自由牛舍 (free stall) 設計。水簾牛舍的設計係利用隧道式負壓抽風配合水氣蒸發散熱來降低牛隻體熱，牛舍為單排式長型自由牛舍，內部長寬高分別為 50 m × 15 m × 2.5 m，配備 48 個餵飼頸項夾及 52 座牛床，每頭牛活動空間約為 9 m^2。以 2.5 m 高的輕鋼架天花板與兩側捲簾達到密閉隧道的效果，牛舍長向底端牆壁由八臺風扇 (48 吋，1 馬力，6 葉片，抽氣量 32,000 m^3/hr) 進行抽氣，相對牆面上設置長高共 20.2 m × 1.8 m 的塑膠蜂巢式水簾片三

片，由馬達啟動水在水簾片的循環流動。為維持舍內通氣，牛舍內隨時最少啟動三台風扇，當舍內溫度高於 26℃時，環境監測電腦系統即同時啟動水簾抽水馬達及抽風風扇，每增加 0.8℃即再啟動一台風扇，最多到七台風扇啟動，預留一台讓風扇可輪流休息。當空氣自水簾片抽入時，經過流動中的水而蒸發降溫並飽含濕度，濕涼的空氣經過牛隻體表吸收體熱後再被抽離牛舍，達到降溫效果。試驗區域使用近水簾的前半段水簾牛舍，但試驗期間以全滿飼養方式以符合牛舍實際使用狀況。

傳統牛舍為頭對頭雙排式自由牛舍，餵飼走道在牛舍中央。牛舍屋頂雙斜，中間高度達 11.8 m，屋頂中間設置太子樓排出熱氣，兩側屋簷最低處 3.4 m。試驗區域為整棟傳統牛舍單邊的一部分，緊鄰等待區與擠乳間，試驗期間也採全滿飼養方式。試驗用區域的長寬分別為 24 m 和 10 m ，提供 24 頭份的頸項夾與 24 座牛床，每頭牛活動空間約為 8.6 m^2。傳統牛舍的降溫措施，包括全日開啟的四臺風扇 (36 吋，2 馬力，3 葉片，抽氣量 26,300 m^3/hr) 及定時啟動的噴水系統，四臺風扇分置於採食走道及牛床上方各兩支，噴水系統設置在採食區頸夾上方，由水管及以色列噴水器組成。每日定時啟動噴水系統共六次，為早上餵飼後的 5:30 - 6:00, 6:30 - 7:00, 10:30 - 11:00, 與下午餵飼後的 15:50 - 16:20, 16:50 - 17:20, 及 17:50 - 18:20，每次 30 分鐘內進行六次循環，每一循環為噴水一分鐘加吹乾四分鐘，噴水一分鐘的水量 (約 2.4 L/min/噴水器) 足以將牛隻淋濕，再由風扇吹乾使體熱蒸發達到牛隻降溫效果。

牛舍外 (大氣)與兩種牛舍內都設置了溫濕度測定器 (HOBO Pro RH/Temp, Onset Computer Corporation, MA, USA)，在民國 94 年 7 月到 9 月共 60 天的試驗期間裡，連續每 0.5 小時測定及紀錄溫濕度一次，每週將資料轉錄到電腦中以進行大氣與牛舍環境參數的累計與分析，並計算每 0.5 小時的 THI。同時，試驗期間在風扇都啟動的最大抽風量狀況下，在兩種牛舍內多個高度、寬度及截面以風速計 (hot wire anemometer)分別測定風速，以瞭解舍內換氣速度。其他詳細牛舍設計與溫控管理，請見本研究另一子題牛舍環境與牛隻生理反應研究報告 (蕭等，2009a)。

3.3.2 試驗動物及飼養管理

選擇乳量 20 kg 以上的荷蘭泌乳牛 42 頭，依照乳量、胎次、泌乳天數與體重等均分為二組，分別群飼於水簾牛舍或傳統牛舍，每組包括瘤胃開窗泌乳牛兩頭。

試驗開始時參試牛隻之平均泌乳天數為 141 ± 60 天 (Mean ± SD，下同)、胎次 2.4 ± 1.4 胎、體重 595 ± 68 kg 及泌乳量 26.2 ± 5.5 kg。乳成分方面為乳脂率 4.01 ± 0.48%、乳蛋白率 3.15 ± 0.27%、乳糖率 4.77 ± 0.21%、總固形物 12.63 ± 0.70% 及體細胞數 23.0 ± 29.1 萬/mL (乳牛群性能改良計畫，Dairy Herd Improvement，DHI)。

泌乳牛每日擠乳兩次，分別為清晨 5:00 與下午 3:15，逐日記錄個別乳量。每日配製兩次完全混合日糧 (totally mixed ration, TMR) 給兩組牛群採食，分別為清晨 4:45 配製 35%量及下午 3:00 配製 65%量，每日下午餵飼前秤重剩料，以調整兩組 TMR 配製量，使達任食並且剩餘量約為其配製量的 5%到 10%。TMR 營養提供 1.15 倍乳量的需要，即 30 kg 泌乳量所需 (NRC, 2001)，組成包括青貯玉米料、盤固乾草、苜蓿乾草、脫水苜蓿粒、魚粉及玉米-大豆粕精料組成，乾物質基礎下的 TMR 計算組成為乾物量 20.1 kg、乾物質 50.8%、精料比 45%、粗蛋白質 16.9%、泌乳淨能 1.58 Mcal/kg、中洗纖維 34.5%、酸洗纖維 21.7%及非纖維性碳水化合物 39.7%。

試驗於民國 94 年七月至九月的夏季執行。第一期 30 天結束後，牛群交換至另一牛舍，繼續第二期 30 天的飼養，兩期間不再安排休息期。

3.3.3 測定項目

3.3.3.1 體重變化：試驗開始、第一期結束與第二期試驗結束，分別連續兩日上午 8:10 過磅。

3.3.3.2 採食活動：每期正式期間，重複三天，先以監視器錄下兩組牛群全日的採食活動，再逐步檢視錄影帶，於每 10 分鐘計算一次兩組牛隻在採食的頭數，換算成佔該牛群總數的比例 (採食頭數 ÷ 總頭數 × 100%)，三日資料平均後繪製一日的採食活動圖，另將一日時間區分為六段，進行兩個牛舍的牛隻採食活動比較。

3.3.3.3 採食量：每日記錄兩組採食量及頭數，包括 TMR 提供量與剩餘量。每期試驗正式期間採集兩次 TMR 個別飼糧，並逐日採樣 TMR 料與兩組剩料。所有樣品先保存於 -20℃，再以 55℃烘乾 48 小時，熱秤得乾物質後計算兩組牛隻 14 天的每日每頭乾物質採食量 (dry matter intake, DMI)。個別樣品烘乾後再各自混合成一個樣品，磨細後進行組成分析與試管乾物質消化率 (IVDMD) 的測定，並計算兩組牛隻各項營養分的採食量。

3.3.3.4 瘤胃消化：每期正式期，重複兩天進行連續 48 小時的瘤胃消化追蹤，分別於 5:30 a.m. (0 hr，清晨擠乳後、餵飼前), 7:30 (2), 9:30 (4), 11:30 (6), 1:30 p.m. (8), 3:30 (10，下午餵飼前、擠乳前), 6:00 (12.5), 8:00 (14.5), 10:00 (16.5), 0:00 a.m. (18.5), 2:30 (21), 及 4:30 (23) 採集兩組各兩頭瘤胃開窗泌乳牛的瘤胃腹囊內容物，以兩層紗布過濾後立即測定瘤胃 pH，並以 50% 硫酸酸化 (1:50 v/v，15 mL 濾液加入 0.3 mL 50%硫酸)，保存於 -20℃，離心後取上清液以氣相層析儀/火燄離子偵測器分析揮發性脂肪酸 (volatile fatty acid, VFA)，及以粗蛋白質比色法分析氨態氮 (NH_3-N) 濃度 (AOAC, 1984)。

3.3.3.5 泌乳性能：每日記錄個別牛隻泌乳量。每期正式期採集三次個別牛 a.m.-p.m. 乳樣，混合個別牛各日上下午乳樣後送本所新竹分所乳品檢驗室，進行乳成分分析。

3.3.4 統計分析

對可以個別測定的體重、乳量、乳成分與產量，以 SAS (2003) 統計軟體的一般線性模式 (general linear model, GLM) 進行交叉設計的統計分析，並以最小均方均值 (least squares means) 表示；對採食活動及瘤胃消化性狀，除以圖示一日之變化外，並將資料經分區段計算成相關介值後再如上述方法進行統計分析；養分採食量以組為單位進行統計分析。在本篇報告中，統計顯著差異水準訂為 5%，當有明顯差異趨勢時，亦在相關表格中列出其 P 值以為參考。

3.4 結果與討論

3.4.1 牛舍環境

試驗期間每日水簾牛舍有 11 小時的舍溫低於 26℃ (表 3.1)。水簾牛舍大部分的白日時間內都有七台抽風扇在啟動中，在最大抽風量與全滿牛隻飼養狀況下，水簾牛舍日間最快風速測定結果為每秒鐘 1.66 m，因此 50 m 長的水簾牛舍每分鐘最高可換氣兩次，但夜間則主以三臺風扇啟動來維持空氣流通與品質，估算水簾牛舍夜間的換氣速度約只達每分鐘 0.85 次，同時夜間水簾的水的啟動也應不多 (因設定 26℃啟動)。

試驗全期每日環境參數的分析結果列於表 1。熱季有牛舍的遮蔭可以降低牛隻熱緊迫，但改善幅度尚不足夠。兩種牛舍的降溫效果以水簾牛舍較佳，水簾牛舍可以 100% 避免舍內溫度超過 30℃ (0 h *vs.* 5.5 h)，增加 69%較低溫的時間 (<

26℃, 11 h *vs.* 6.5 h)，並將一日最高溫度自傳統牛舍的 31.1℃拉低到 28.7℃ (-2.4℃)，一日均溫自傳統牛舍的 27.8℃拉低到 26.6℃ (-1.2℃)。在濕度方面，國內環境非常潮濕，夜間大氣就約有八個小時的相對濕度已高於 90%，加上白天水簾的啟動，使水簾牛舍內全日的相對濕度都維持在高檔的 93.5%以上；而大氣與傳統牛舍的相對濕度則有節律變化，與氣溫成反向相關，相對濕度隨著日溫的增加而下降，傳統牛舍相對濕度在中午氣溫最高時可以降低到 73% 左右，夜間也升高到 90% 以上。THI 測定結果顯示，兩種牛舍的降溫都無法提供牛隻舒適的生活環境 (≤ 72 都為 0 h)，但還好也都未讓牛隻處於嚴重的熱緊迫狀況 (> 84 階段也都為 0 h)，兩種牛舍牛隻一直處於輕度到中度熱緊迫中，一日中約有 69% (水簾牛舍) 或 79% (傳統牛舍)的時間，牛隻處於中度熱緊迫中 (78 < THI ≤ 84)，水簾牛舍環境可以增加 50%輕度熱緊迫時間 (72 < THI ≤ 78, 7.5 h *vs.* 5 h)。由環境參數的測定得知，水簾牛舍的蒸發散熱方式在降低舍溫與 THI 的效果上優於傳統牛舍，而且主要作用於白日時段，但高濕度與低的換氣速度也帶來極大隱憂。

表 3.1 2005 年大氣、傳統牛舍與水簾牛舍環境參數分析 [1]

Table 3.1 Environmental profiles of ambient, conventional barn, and water-padded barn during the hot summer in 2005[1]

Items	Categories	Ambient	Conventional barn	Water-padded barn
Temperature, ℃	T ≤ 26	4.0	6.5	11.0
	26 < THI ≤ 30	12.0	12.0	13.0
	T > 30	8.0	5.5	0
RH,[2] %	RH ≤ 70	5.5	0	0
	70 < RH ≤ 80	4.0	6.0	0
	80 < RH ≤ 90	6.5	4.5	0
	> 90	8.0	13.5	24.0
THI[3]	THI ≤ 72	0	0	0
	72 < THI ≤ 78	4.0	5.0	7.5
	78 < THI ≤ 84	17.0	19.0	16.5
	> 84	3.0	0	0
Temperature, ℃	Mean	28.6	27.8	26.6
	Maximum	32.9	31.1	28.7
	Minimum	25.6	25.4	25.0
RH, %	Mean	81.7	88.5	97.5
	Maximum	92.9	96.8	99.3
	Minimum	63.83	73.1	93.5
THI	Mean	80.6	80.2	79.5
	Maximum	84.4	83.5	82.7
	Minimum	77.3	77.3	76.9

[1] Temperature and relative humidity were recorded by HOBO Pro RH/Temp recorders hung in these three environments every 30 min. from July to September in 2005.

[2] RH: relative humidity.

[3] THI: temperature-humidity index, $THI = 9/5 \times T + 32 - 0.55 \times (1 - RH) \times (9/5 \times T - 26)$, that T represents temperature in ℃ and RH in decimal (NOAA, 1976).

3.4.2 飼糧組成與採食

試驗正式期間的 TMR 配方、個別飼糧組成與 TMR 組成的分析結果列於表 3.2 (乾基)。實際調配的 TMR 組成與計算值相近，兩種牛舍 TMR 採樣的分析結果也顯示組成相近。兩組牛隻一日內每 10 分鐘的採食活動繪於圖 3.1，牛隻在兩次新鮮 TMR 餵飼後的採食活動明顯增加，尤其是清晨的餵飼，有高達 75% 的牛群一齊採食，採食活動高峰持續約 1.5 小時，下午餵飼後的採食活動高峰也可以近 75% (傳統牛舍組) 或近 50% (水簾牛舍組)，但持續時間較久，一日內其餘時間的採食活動則多在 20%以下。將一日分成數個時間區段 (表 3.3)，水簾牛舍環境顯著降低兩個時段的牛隻採食活動 ($P < 0.05$)，即上午約 7:30 – 11:00 (10.9% *vs.* 19.2%) 及下午約 3:30 新鮮 TMR 餵飼後的兩小時 (35.7% *vs.* 62.1%)，水簾牛舍牛隻在兩時段的採食活動都只有傳統牛舍牛隻的 57%，水簾牛舍牛隻全日平均採食活動也較傳統牛舍的降低了 19%，試驗結果顯示本次試驗水簾牛舍所提供的環境確實會減低牛隻的採食行為。兩種牛舍環境對牛隻養分採食量的影響尚未達顯著差異水準 (表 3.4)，但數字上都以水簾牛舍牛隻的攝取量較低。水簾牛舍與傳統牛舍牛隻的每日每頭乾物質採食量分別為 17.0 kg 與 18.4 kg，水簾牛舍使乾物質採食量降低 8%，即每日每頭達 1.4 kg，因此使其他營養分的攝取量也隨之減少，尤其是非纖維性碳水化合物 (non-fibrous carbohydrate, NFC) 的採食量 ($P < 0.08$)，營養分採食量的降低應緣自於水簾牛舍環境減少牛隻的採食活動所致。

表 3.2　水簾牛舍紓解荷蘭泌乳牛熱緊迫試驗之完全混合日糧配方及組成 (%，乾基)[1]

Table 3.2　TMR formulation and compositions fed to Holstein lactating cows in water-padding barn evaluation experiment (%, DM basis)[1]

Ingredients[2] (no. pooled for analyses)	DM% in TMR	Chemical compositions and *in vitro* digestibility, %[3]									
		DM	CP	ADF	ADL	NDF	EE	Ash	Ca	P	IVDMD
Corn silage (4)	31.1	26.8	10.9	36.8	3.36	56.6	3.48	7.9	0.35	0.24	56.7
PG hay (4)	4.3	89.6	4.5	43.4	5.66	75.4	1.22	5.4	0.24	0.06	47.8
Alfalfa hay (4)	12.8	88.2	17.7	37.7	7.17	45.7	1.66	8.2	1.13	0.19	63.5
Dehy AP (4)	6.8	93.0	20.8	32.1	7.59	43.7	2.69	10.7	1.90	0.27	65.6
Fish meal (4)	0.87	89.5	72.2	1.1	0.19	12.4	8.50	17.5	4.10	2.56	81.2
Concentrate (4)[4]	44.2	91.2	23.2	5.6	0.49	14.3	1.82	8.1	0.87	0.65	89.2
WP TMR (30)		51.9	17.2	25.2	3.27	39.5	2.74	7.7	0.78	0.40	69.9
C TMR (30)		51.5	17.6	24.4	3.20	37.7	2.67	7.7	0.82	0.43	71.2

[1] Same TMR was offered to both groups *ad libitum* Individual feed ingredient was sampled two times a period and pooled for analyses. TMR was sampled at the last 15 days each period and pooled for analyses.

[2] PG hay: pangolagrass hay, Dehy AP: Dehydrated alfalfa pellet, WP: water-padding barn, C: conventional barn, TMR: totally mixed ration.

[3] DM: dry matter, CP: crude protein, ADF: acid-detergent fiber, ADL: acid-detergent lignin, NDF: neutral-detergent fiber, EE: ether extract, IVDMD: *in vitro* dry matter digestibility.

[4] Each metric ton of concentrate was constituted by 575 kg of ground corn, 305 kg of soybean meal, 20 kg of fish meal, 50 kg of molasses, 4 kg of limestone, 8 kg of dicalcium phosphate, 25 kg of sodium bicarbonate, 5 kg of magnesium oxide, 3 kg of salt and 5 kg of vitamin and mineral premix (as fed basis).

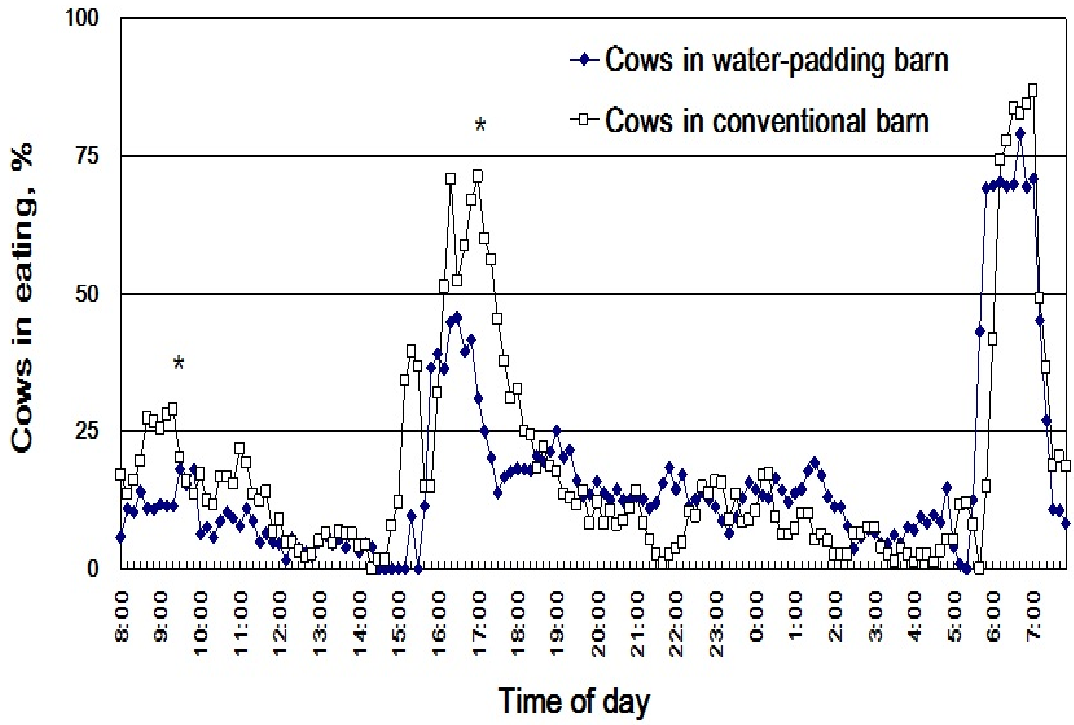

圖 3.1　水簾牛舍環境對熱季荷蘭泌乳牛每日採食活動之影響。

Figure 3.1　Effect of water-padding barn environment on the intake activities of Holstein lactating cows during hot summer. A total of 42 cows were assigned in a cross-over design with 30 days a period. Three 24-h intake activities each period were recorded by video and counted every 10 min. Number of cows eating was calculated as the percentage of each group. Asterisks indicated the higher intake activities of cows in conventional barn at those two time segments ($P < 0.05$).

表 3.3　水簾牛舍環境對熱季荷蘭泌乳牛採食活動之影響 [1]

Table 3.3　Effect of water-padded barn environment on the intake activities of Holstein lactating cows during hot summer[1]

Time segments	Conventional barn	Water-padded barn	SEM[2]	Sig.[3]
No. of observations	2	2		
Daily average, %	22.6	18.3	1.6	NS
2 hrs after 5:30 feeding, % (after a.m. milking)	56.9	58.4	9.0	NS
Around 7:30 – 11:00, %	19.2	10.9	0.4	*
Around 11:00 – 14:00 , %	8.0	5.4	2.4	NS
2 hrs after 15:30 feeding, % (after p.m. milking)	62.1	35.7	0.5	*
Around 17:30 – 22:00, %	16.2	16.4	2.7	NS
Around 22:00 – 5:00 next day, %	8.1	11.7	1.0	NS

[1] A total of 42 cows were randomly assigned into two barn treatments in a cross-over design with 30 days a period. Cows were group-fed in both free stall barns. Three 24-h intake activities each period were recorded by video and counted every 10 min. Number of cows eating was calculated as the percentage of each group.

[2] SEM: standard error of the mean.

[3] Significant level: NS: non-significant, $P > 0.05$; * $P < 0.05$.

表 3.4　水簾牛舍環境對熱季荷蘭泌乳牛養分採食量之影響 [1]

Table 3.4　Effect of water-padded barn environment on the daily nutrient intakes of Holstein lactating cows during hot summer[1]

Items[2]	Conventional barn	Water-padded barn	SEM[3]	Sig.[4]
No. of observations	2	2		
DM intake, kg	18.4	17.0	0.29	NS
CP intake, kg	3.27	2.97	0.09	NS
ADF intake, kg	4.41	4.20	0.10	NS
NDF intake, kg	6.78	6.58	0.14	NS
EE intake, kg	0.50	0.47	0.01	NS
NFC intake, kg	6.45	5.68	0.06	(P = 0.08)

[1] A total of 42 cows were randomly assigned into two barn treatments in a cross-over design with 30 days a period. Cows were group-fed. TMR and refusal were weighted, sampled and dried daily for dry matter analyses from the last 15 days each period and pooled for the other nutrients analyses.

[2] DM: dry matter, CP: crude protein, ADF: acid-detergent fiber, NDF: neutral-detergent fiber, EE: ether extract, NFC: non-fibrous carbohydrate.

[3] SEM: standard error of the mean.

[4] Significant level: NS: non-significant, $P > 0.05$; All nutrients intake were not affected by barn environment.

3.4.3 瘤胃消化

兩種畜舍對荷蘭泌乳牛瘤胃內容物 pH、氨態氮與 VFA 的日變化影響繪於圖 3.2。兩組開窗牛每日瘤胃 pH 最高點發生在清晨 4:30 或 5:30 的餵飼前，pH 值約為 6.38；每日瘤胃 pH 最低點，水簾牛舍環境發生在上午 7:30 的 5.83，傳統牛舍環境發生在夜間 8:00 的 5.85。以餵飼後瘤胃 pH 下降的幅度來比較，水簾組降低幅度較大的是在清晨餵飼後，而傳統牛舍組在下午餵飼後有較大的 pH 降低幅度，此現象與兩組牛隻採食活動的多寡模式相符 (圖 3,1 與表 3.3)。傳統牛舍飼養環境使牛隻瘤胃氨態氮濃度在下午餵飼後明顯升高 (圖 3.2 (B))，牛隻瘤胃 VFA 濃度在凌晨到清晨階段高於水簾牛舍牛隻 (圖 3.2 (C))，也都符合兩組牛隻採食活動的多寡模式。將三項瘤胃代謝產物進行分析，結果顯示兩種牛舍對牛隻瘤胃消化的影響相近，包括瘤胃 pH、氨態氮與 VFA 的日加權平均、最高最低的變化幅度與乙酸、丙酸及丁酸的莫耳濃度等 ($P > 0.05$，表 5)。綜合瘤胃消化的表現，水簾牛舍環境減低牛隻採食活動與乾物質採食量，瘤胃的消化作用有受到影響，但影響尚未達到顯著差異水準。

3.4.4 泌乳性能

本次試驗採用交叉設計，圖 3 顯示兩組牛群在全期試驗的逐日乳量變化。第一群牛群在試驗第一期飼養於傳統牛舍，其 30 日的乳量穩定的維持在 27 kg 上下，但交叉轉換到第二期的水簾牛舍飼養環境後，乳量快速得降低到 22 kg 左右，降低幅度約 5 kg；反觀第二組牛群在第一期試驗期飼養於水簾牛舍，其乳量即自開始的 26.2 kg 降至 25 kg 而後維持，降低約 1.2 kg 左右，當交叉轉換到第二期的傳統牛舍飼養環境後，乳量仍可以維持在 24 kg 範圍，降低幅度僅 1 kg 左右，因此由交叉設計可以明確看到水簾牛舍飼養環境對牛群泌乳量的不利影響。

經過兩期全程試驗，去除生病等問題牛隻，有 33 頭泌乳牛完成試驗。兩種牛舍環境不影響牛隻的體重變化 (表 3.6)，但水簾牛舍飼養環境極顯著得降低 10%的牛隻 4%乳脂校正乳量 (-2.6 kg, 23.1 kg *vs* 25.7 kg, $P < 0.001$)、降低 1.8%的乳蛋白質率 (3.27% *vs* 3.33%, $P < 0.05$) 與 1.5%的總固形物濃度 (12.57% *vs* 12.76%, $P < 0.01$)；由於乳量與乳成分的降低，使每日每頭牛乳成分的產量也都極顯著的低於傳統牛舍組 9%到 10% ($P < 0.001$)，包括乳脂肪、乳蛋白質、乳糖與總固形物，試驗結果顯示此次水簾牛舍環境顯然抑制了牛隻泌乳性能的表現。

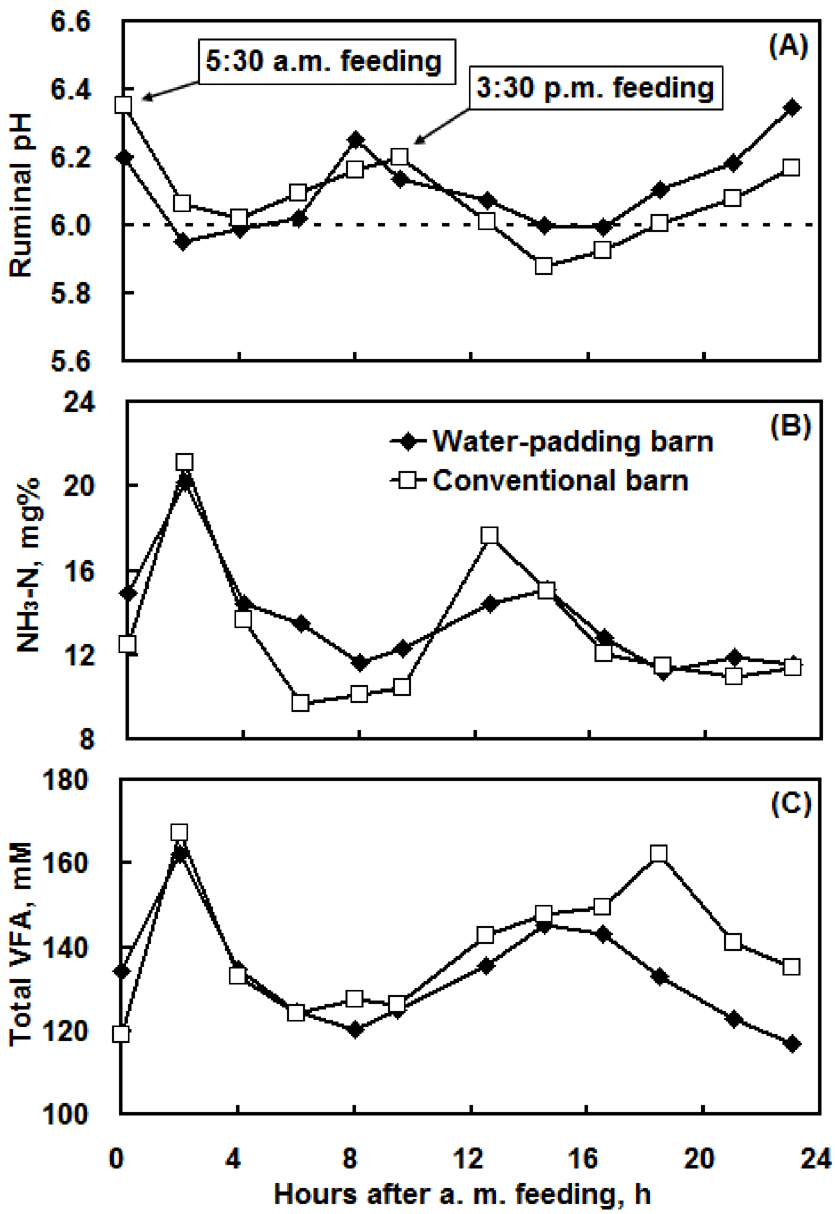

圖 3.2　水簾牛舍環境對熱季荷蘭泌乳牛瘤胃內容物 pH (A)、氨態氮濃度 (B) 與揮發性脂肪酸濃度 (C) 之影響。

Figure 3.2　Effect of water-padded barn environment on the diurnal rumen pH (A), NH_3-N (B) and volatile fatty acid (VFA) (C) levels of Holstein lactating cows during hot summer.

表 3.5　水簾牛舍環境對熱季荷蘭泌乳牛瘤胃內容物 pH、氨態氮與揮發性脂肪酸濃度之影響 [1]

Table 3.5　Effect of water-padded barn environment on the rumen pH, NH_3-N and volatile fatty acid (VFA) of Holstein lactating cows during hot summer[1]

Items	Conventional barn	Water-padded barn	SEM[2]
No. of cows observed	4	4	
Rumen pH			
Diurnal average	6.07	6.10	0.03
Highest value	6.37	6.39	0.02
Lowest value	5.85	5.83	0.04
Duration < 6.0, h	6.6	6.9	2.7
Rumen NH_3-N, mg%			
Diurnal average	13.0	13.8	0.4
Highest value	21.2	21.9	1.1
Lowest value	8.3	8.3	0.2
Rumen VFA			
Acetate, molar%	70.0	68.7	1.1
Propionate, molar%	16.2	17.5	1.2
Butyrate, molar%	10.4	10.1	0.2
C_2/C_3	4.36	4.11	0.24
Total VFA, mM	140.5	133.5	5.2

[1] Two consecutive 24-h rumen content samplings were conducted each period with two rumen cannulated lactating cows in each barn. Samples were immediately filtrated for pH measurement and acidified and frozen for later NH_3-N and VFA analyses.

[2] SEM: standard error of the mean; All rumen measurements were not affected by barn environment, $P > 0.05$.

泌乳牛對熱緊迫非常敏感，尤其是高產牛。當牛隻無法有效排熱，將導致體溫升高、呼吸次數增加、採食量降低、乳量下降與繁殖性能低落等。本次試驗水簾牛舍環境降低了牛隻的採食活動、採食量與乳量，同時進行的牛舍環境參數與牛隻生理反應研究 (蕭等，2009)，得知兩種牛舍環境仍然使泌乳牛群 74% 的時間

處於中度熱緊迫 (78 < THI ≤ 84) 狀況下，水簾牛舍牛隻 4 a.m. 的呼吸數高於傳統牛舍牛隻 (每分鐘 62 次 *vs.* 50 次，$P < 0.001$)，2 p.m. 兩組牛隻呼吸數都增高為每分鐘 72 次，再者，水簾牛舍牛隻清晨與下午的直腸溫度都高於傳統牛舍牛隻，下午直腸溫度分別達到 39.75℃與 39.47℃ ($P < 0.05$)。綜合牛隻反應，試驗期間兩組牛隻都處於熱緊迫中，水簾牛舍環境的熱緊迫更明顯高於傳統牛舍，推測持續高濕度與夜間的低換氣速度可能是主要問題。

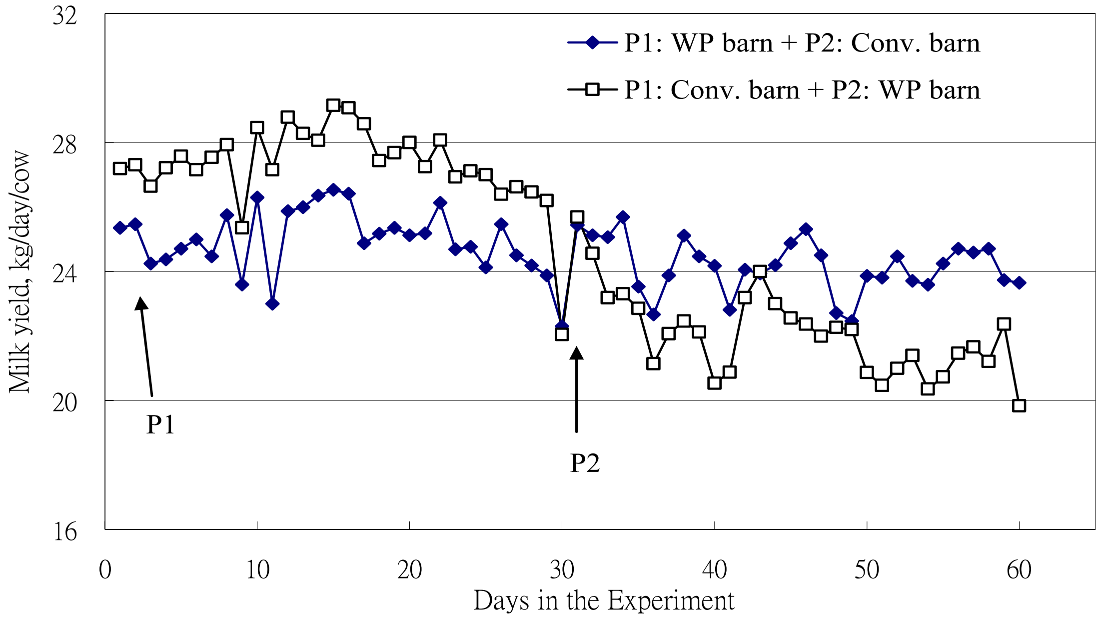

圖 3.3　在交叉試驗設計下呈現的水簾牛舍環境對熱季荷蘭乳牛泌乳量之影響。

Figure 3.3　Effect of water-padded barn environment on the daily milk yield of Holstein lactating cows during hot summer in a cross-over design. Initial milk average of all cows attended the experiment was 26.2 kg a day. Cows in the conventional (Conv.) barn in period one (□) had average milk yield around 27 kg a day. When they transferred to the water-padded (WP) barn in period 2, milk yield dropped to about 22 kg, 5 kg milk decrease was noted. On the other hand, cows in the WP barn at period one (♦) had milk yield drop to around 25 kg per day. When they changed to the conventional barn, milk yield could be held around 24 kg a day. Only 1 kg decrease was found. Barn effect on milk yield was clearly illustrated from the cross-over design.

表 3.6　水簾牛舍環境對熱季荷蘭乳牛泌乳性能之影響 [1]

Table 3.6　Effect of water-padded barn environment on the lactation performance of Holstein cows during hot summer[1]

Items[2]	Conventional barn	Water-padded barn	SEM[3]	Sig.[4]
No. of cows observed	33	33		
Initial BW, kg	599	595	3	NS
Daily BW gain, kg/d	-0.004	0.083	0.104	NS
Actual milk yield, kg/d	25.7	23.3	0.4	***
4% FCM, kg/d	25.7	23.1	0.4	***
Milk fat, %	4.02	3.93	0.05	NS
Milk fat, kg/d	1.02	0.92	0.02	***
Milk protein, %	3.33	3.27	0.02	*
Milk protein, kg/d	0.84	0.76	0.01	***
Milk lactose, %	4.79	4.75	0.02	NS
Milk lactose, kg/d	1.22	1.11	0.02	***
Milk total solid, %	12.76	12.57	0.05	**
Milk total solid, kg/d	3.23	2.94	0.05	***
SCC,[2] $*10^4$/mL	52.2	63.7	10.9	NS

[1] A total of 42 cows were randomly assigned into two barn treatments in a cross-over design with 30 days each period. Cows were group-fed. Milk yields were recorded daily and three individual a.m.-p.m. milk were sampled for composition analyses each period. Thirty three out of 42 head cows successfully finished the experiment.

[2] BW: body weight, FCM: fat corrected milk, SCC: somatic cell count.

[3] SEM: standard error of the mean.

[4] Significant level: NS: non-significant, $P > 0.05$; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

與屬於美國濕熱地區的試驗比較，國內氣候環境的相對濕度應更高，本次試驗的換氣速度也相當偏低。Smith *et al.* (2006a,b) 對水簾牛舍的評估是正面的，其隧道式蒸發散熱可減少 84%牛隻曝露於中度熱緊迫 (80 < THI < 90) 的時間，增加 11% 的牛隻採食量及 2.6 kg 的乳量，同時降低 27% 到 49% 的生乳體細胞數。

該報告的牛舍硬體設計與本次水簾牛舍類似，但規模較小 (20 頭成牛牛舍，長寬高分別為 27.5, 9.2, 及 2.1-2.4 m)，其水簾牛舍多點測定的平均風速達每秒鐘 1.93 m，畜舍每分鐘換氣可達到 4.2 次，都高於本次試驗日間最高的風速每秒鐘 1.66 m、每分鐘兩次的換氣速度及夜間每分鐘 0.85 次的換氣速度。在相對濕度方面，Smith *et al.* (2006a,b) 的報告中提到水簾牛舍白天的相對濕度也在 90% 以上，夜間大氣相對濕度資料未提供，夜間關閉水簾不用只進行抽風換氣 (四台風扇於氣溫 18.3, 21.1, 23.9, 與 26.7℃依序啟動)，報告中對照組牛舍白天的相對濕度為 64.4 到 71.3%，低於本次試驗對照組。

相對濕度是一項非常重要的環境因素。環境相對濕度影響牛隻舒適的氣溫，在 THI 72 牛隻舒適與否的關卡時，若相對濕度較低時舒適氣溫可以為 27℃氣溫；相對濕度較高時則降低到 22℃氣溫，牛隻即開始感受到熱緊迫 (Armstrong, 1994; West, 2003)。濕度高可使高溫的嚴重性更惡化，當氣溫與相對濕度增加時，牛隻採食量降低；而高溫高濕下的牛隻採食量會較高溫低濕的狀況更低 (Johnson *et al.*, 1963)。以氣控室進行試驗，在氣溫 -11℃到 4℃範圍內調整相對濕度，對牛隻熱生成、經呼吸道的蒸發散熱、呼吸速度與直腸溫等都沒有一致性的影響；但在 24℃到 38℃範圍時，增加相對濕度就增加乳牛直腸溫與呼吸速度，其一原因是低溫時空氣水分含量少，而高溫空氣中含有大量水分，因此高溫高濕會衝擊到牛隻將熱以體表水分蒸發的能力 (Kibler and Brody, 1953)，當相對濕度自 30% 增加至 90% 時，流汗速率自每平方公尺體表面積每小時的 500 g 水分降低到 60 g (Maia *et al.*, 2005b; Hillman, 2009)。風速是另一項重要的環境氣候因素，足夠的風速可以有效降溫。蒸發散熱必須有足夠的風速來帶走體表濕度，研究顯示，單獨噴霧處理無法改善牛隻的採食及泌乳 (Bucklin *et al.*, 1989)，噴霧降溫所配合的風速不夠時，微細水霧反而會在牛隻體表毛髮上形成一層絕緣，負面影響熱的蒸發排散 (Hahn, 1985)，Missouri 研究報告指出，比較單獨遮蔭與遮蔭+噴霧+吹風的降溫效果，在 04:00 與 16:00 時的相對濕度分別為 77.7% 與 43.3% 及乾球溫度分別為 22℃與 30.9℃環境下，噴霧加上吹風可顯著增加 8.6% 乳量 (23.3 kg *vs.* 25.3 kg, *P* <

0.05)。當風速自每秒 0.2 m 增加至每秒 0.9 m 時，流汗速率可自每平方公尺體表面積每小時的 75 g 水分增加到 350 g (Hillman *et al*., 2001; Hillman, 2009)。

處於熱緊迫中，動物會增加夜間少量多餐的採食活動 (Hahn, 1999)，因此重視熱季夜間降溫與餵飼是被推薦的管理策略 (Fuquay, 1981; Keister *et al*., 2004)，研究顯示夜間乾球溫度若能低於 21℃達 3 到 6 h，則可以將由熱引致的乳量下降程度最小化 (Igono *et al*., 1992)，將以色列強度管理泌乳牛群 (乳量 42 kg，擠乳四次，餵飼四次) 的白天餵飼量減少，也得到加強夜間餵飼可以提高飼糧能量利用效率的結果 (Aharoni *et al*., 2005)。

3.5 結論與建議

臺灣高溫高濕環境造成畜禽嚴重的熱緊迫問題。水簾牛舍原本設計用於乾燥地區的降溫，在臺灣是否可以用來紓解泌乳牛夏季熱緊迫，是本試驗希望探討與評估的嘗試。民國 94 年第一年的評估顯示，日間最高換氣速度每分鐘兩次的水簾牛舍環境，雖然可以較有效的降低白日舍溫與 THI，但對牛隻性能表現確實有負面影響，牛隻採食活動、採食量、乳量及乳成分產量都明顯降低，水簾牛舍全日持續高的相對濕度 (≥ 93.5%) 與偏低的換氣速度，很可能使牛隻無法順利自體表排熱，熱負荷高造成採食下降與泌乳性能低落，水簾牛舍整體設計仍亟待修改，改善方向將朝增加換氣速度或白日水簾+夜間運動場的搭配方式等進行。

第四章 以水簾牛舍紓解荷蘭泌乳牛熱緊迫之可行性評估

III 增加換氣速度與噴水降溫之效果

4.1 中文摘要

在高濕地區以水的蒸發散熱來紓解熱緊迫的適當性一直被質疑，臺灣夏季高濕高熱一直是荷蘭泌乳牛性能表現的瓶頸，本次試驗目的在評估高濕地區應用水簾牛舍紓解泌乳牛熱緊迫的可行性。試驗於 2006 年 8 月到 10 月進行，在一個 3 x 3 拉丁方設計下，36 頭荷蘭泌乳牛分三組飼養於隧道式抽風配合水簾降溫的自由牛舍 (簡稱水簾組，WP barn) 、水簾+噴水降溫牛舍 (簡稱水簾+噴水組，WP+SP barn) 或採食走道噴水吹風的傳統自由牛舍 (風扇+噴水組，Fan+SP barn，對照組)，試驗每一期 21 日。三種牛舍環境的日間風速分別為每秒鐘 2.38, 2.06, 及 1.23 m，水簾兩組日間換氣速度分別為每分鐘 2.8 次與 2.4 次，水簾兩組在降低牛舍日間溫度與溫濕度指數的效果較優於傳統牛舍，每日可增加 4.2 小時低於 26℃的時間，但全日相對濕度高達 96% 以上。水簾兩組牛隻清晨三點的呼吸數與體表溫度顯著高於風扇+噴水組牛隻；水簾環境降低血清膽固醇濃度、ALP 與 ALT 活性，但不影響血液 CO_2 分壓。水簾組牛隻陰道溫度持續高，但噴水處理有效紓解牛隻熱緊迫，噴水兩組牛隻陰道溫度隨噴水與擠乳處理後明顯下降，幅度達到 0.4°C 到 0.6°C。三種牛舍環境對牛隻採食活動、瘤胃消化及泌乳性能的影響相近，但水簾兩組牛隻有顯著較高的採食量，且水簾+噴水組牛隻乳量已有高於對照組的趨勢 (25.4 kg *vs*. 24.7 kg, $P = 0.10$)。本次試驗的三種牛舍環境尚無法完全紓解泌乳牛熱緊迫 (THI > 72)，但經由增加風速與噴水處理，已解決 2005 年第一代水簾牛舍對牛隻採食與乳量的負面影響，因此水簾牛舍在高濕地區應用的可行性是可以期待的，增加風速為再進一步改進的關鍵。

4.2 緒言

由於龐大的體軀與快速的代謝速度，泌乳牛對熱緊迫非常敏感，尤其是高產牛。環境因素如氣溫、相對濕度、太陽輻射與風速等相互影響，當使環境有效溫度 (effective temperature) 高於動物的中溫帶 (thermoneutral zone) 或舒適帶 (comfort zone) 溫度，就會造成熱緊迫 (Bianca, 1962)。牛隻為紓解熱緊迫，以尋求遮蔭、增加飲水、排汗、排尿與喘氣等來散熱 (Bucklin *et al*., 1991; Smith *et al*., 2006a)，若仍無法有效排熱，則導致體溫升高、採食量下降、乳量下降與繁殖性能低落等等 (West, 2003)。

Beede and Collier (1986) 建議自牛舍環境改善、耐熱品種選拔及營養管理三方面來減緩乳牛熱緊迫，其中牛舍環境改善是最有效與直接的方法。臺灣是一個位於亞熱帶的海島，近十年夏季月平均氣溫與相對濕度分別達到 27.1℃與 84.0% (表 4.1)，夏季除了高溫，嚴重的高濕問題更甚於世界其他很多地區，因此熱緊迫一直是乳牛性能表現極大的瓶頸與挑戰。提供遮蔭的牛舍是本地乳牛飼養的必備設備，李等 (1999) 引入以色列噴水吹風降溫設施，也有效降低牛隻直腸溫度與呼吸數並且增加採食量，但目前即使是經營管理良好的酪農戶，其牛舍內 THI 在涼、暖與熱季也分別達到 66.3, 75.7, 與 79.8，表示全年仍有 2/3 的時間，牛隻仍處於輕度到中度熱緊迫的狀態 (陳等，2009)。開放式牛舍一直有鳥類進駐的問題，為有效降溫與防疫，一種密閉式降溫的牛舍成為我們努力的方向。隧道式水簾抽風畜舍已相當成功的運用於家禽的飼養上，但在乳牛的應用上則是較新的嘗試。利用水的蒸發散熱在乾燥地區有效紓解牛隻熱緊迫 (Bengtsson and Whitaker, 1988; Ryan *et al*., 1992)，但這種方法增加牛舍內相對濕度，在濕熱地區的適用性一直有著很多的疑慮與辯論，相關試驗也相當缺乏。美國 Mississippi 州的夏季較為濕熱，Smith *et al*. (2006a,b) 比較隧道式蒸發散熱與蔭棚+風扇+噴水兩種降溫牛舍對泌乳牛之影響，得到隧道式蒸發散熱可以有效減少 84%牛隻曝露於中度熱緊迫 (THI > 80)的時間，增加牛隻採食量與乳量，同時顯著降低乳中體細胞數，顯示隧道式蒸發散熱系統在較濕的地區也可以有效紓解牛隻熱緊迫。

2004年在臺灣畜產試驗所完成一棟水簾牛舍的建築，2005年第一代水簾牛舍評估試驗結果顯示，與牛舍+風扇+噴水對照組比較，在日間最高1.66 m 風速 (日間最高換氣每分鐘 2 次，夜間估算 0.85次) 及全日高於 93.5% 相對濕度的環境下，水簾牛舍雖然可以較有效的降低日間舍溫與 THI，但卻增加牛隻熱負荷，牛隻呼吸次數與直腸溫度增加，採食活動降低、乾物質採食量降低7.6%與乳量降低10.1% (蕭等, 2009a,b)，風速不足與高相對濕度推測是增加牛隻熱負荷的原因。噴水吹風是最經濟有效的牛隻降溫措施 (Hillman *et al*., 2005)，因此經由增加一倍抽風扇數量、加入噴水處理與增加側面遮蔭棚， 2006年再次評估第二代水簾牛舍在臺灣高濕熱環境下紓解泌乳牛熱緊迫的可行性。

表 4.1 近 10 年臺南新化地區環境溫溼度統計 (2000 - 2009，B2N89 號氣象台)

Table 4.1 Monthly averages of air temperature and relative humidity in Tainan County of Taiwan from 2000 to 2009 (Meteorological Station B2N89)

	Temperature, ℃			Relative humidity, %		
Season	Mean[1]	Maximum	Minimum	Mean	Maximum	Minimum
No.	60	60	60	60	60	60
Cool[2]	20.2 ± 2.6[3]	31.4 ± 2.2	10.6 ± 3.5	80.5 ± 3.6	99.4 ± 1.2	36.0 ± 8.1
Hot	27.1 ± 1.1	35.1 ± 1.2	21.1 ± 2.3	84.0 ± 3.5	99.9 ± 0.3	46.2 ± 8.9

[1] Mean data were calculated from days in a month and maximum and minimum data were the extreme data from each month.

[2] Cool season included from Nov. to April and hot season included from May to Oct.

[3] Mean ± SD.

4.3 材料與方法

4.3.1 牛舍處理

試驗於 2006 年 8 月至 10 月在臺灣南部的畜產試驗所乳牛試驗場進行，採用一個 3 x 3 拉丁方設計，每期 21 天，前 14 天為適應期，後 7 天為正試驗資料收集期。試驗處理為三種降溫牛舍，包括對照組的傳統自由牛舍，配置風扇與噴水降溫處理 (簡稱風扇+噴水牛舍組，Fan+sprinkler barn，Fan+SP barn)、隧道式抽風降溫水簾自由牛舍 (簡稱水簾牛舍組，water-padding barn，WP barn) 及水簾自由牛舍再配置噴水降溫處理 (簡稱水簾+噴水牛舍組，WP+sprinkler barn，WP+SP barn)。

Fan+SP barn 為臺灣目前普遍使用牛舍型式，屋頂雙斜並設置通氣太子樓，牛舍屋頂中間高度 11.8 m，兩側屋簷最低處 3.4 m，屋頂為厚度 0.45 mm 白色鋁鋅鋼板加上隔熱層。牛舍總面積為 60 × 30 m^2，試驗期間採全滿飼養方式，參試牛隻活動面積 12 m × 10 m。Fan+SP barn 於採食走道及牛床上方設置共四臺全日開啟的風扇 (2.0 HP，直徑 36’’，3 葉片，風量 26,300 m^3/h)，噴水系統設置在採食區上方，分別於 8:00, 9:00, 10:00, 15:50, 16:50, 17:50, 22:00, 及 23:00 等合計啟動八次，每次 30 分鐘內有 6 次循環，每次循環噴水 1 分鐘加吹乾四分鐘，噴水量為 2.4 L/min。水簾牛舍係利用隧道式負壓抽風配合濕涼的入氣來帶走牛隻體熱。水簾牛舍為長型自由牛舍 (蕭等, 2009a)，內部總容積為 50 m (L) × 15 m (W) × 2.5 m (H)，屋頂為

雙層具散熱透氣孔的白色鋁鋅鋼板。水簾為三層立體蜂巢狀塑膠製成，三片水簾形成面積 20.2 m (L) × 0.45 m (W) 1.8 m (H) 的 L 型牆，在牛舍另一端牆面，設置兩排共 16 臺與 Fan+SP barn 相同的抽風扇。牛舍兩側以厚塑膠簾達到密閉隧道的效果。水簾牛舍通風量以 Fancom F-Central 電腦系統 (Fancom Agri-Computers, Panningen, Netherland) 做線性控制，當舍溫 ＜26℃時，設定最低通風量為 6 臺風扇啟動，以確保新鮮空氣流量，舍溫每增加 0.8℃即增加 1 組風扇 (2 臺) 啟動，直到最高通風量的 14 臺風扇，保留一組風扇可輪流休息。水簾上水流的啟動馬達也以溫度 ＞26℃後啟動。試驗期間水簾牛舍均分成四大欄，採全滿 48 頭泌乳牛的飼養方式。最近水簾的一欄為水簾組，另於較近風扇的第三欄安裝與對照組相同的噴水系統及運轉流程，為水簾+噴水組。

4.3.2 試驗動物飼養管理

本研究涉及之動物試驗於行政院農業委員會畜產試驗所執行，動物之使用、飼養及實驗內容係依據行政院農業委員會畜產試驗所實驗動物管理委員會批准之試驗準則進行。

依照乳量、胎次、泌乳天數與體重等資料，將 36 頭泌乳牛逢機均分為三組，輪流飼養於三種牛舍內，每組並包括一頭瘤胃開窗泌乳牛。試驗前牛隻的平均泌乳天數、胎次、體重與乳量分別為 143 ± 69 天、1.5 ± 0.9 胎、540 ± 67 kg 及 24.5 ± 4.2 kg。於每日 5:00 及 15:30 兩次擠乳；7:00 (1/3) 與 15:00 (2/3) 兩次提供新鮮 TMR 任食。牛群 TMR 提供 28 kg 泌乳量所需營養 (NRC 2001)，配方包括 11.1% 的青貯玉米、20.6% 的青貯狼尾草、18.2% 的苜蓿、15.3% 的啤酒粕+磨碎玉米青貯料、9.0% 的黃豆殼粒及 25.8% 的穀類精料 (乾基)，飼糧計算組成為 DM 38.2%、CP 16.2%、NE_L 1.54 Mcal/kg 及 NDF 42.6%。試驗開始、換組與試驗結束時，分別連續兩日 8:10 餵飼前過磅。

4.3.3 牛舍環境參數測定

在水簾牛舍四欄前後位置，分別在牛頸夾及牛床上方離地 2 m 處，自天花板懸掛一溫濕度測定器 (HOBO Pro RH/Temp, Onset Computer Corporation, MA, USA)，共計 8 個，在對照組試驗欄前後的相同位置與高度，懸掛 4 個感應器。設定試驗 63 天內每 0.5 h 測定一次，每週將資料轉錄到電腦中以分析三種牛舍中每日溫度與相對濕度的變化，並計算溫濕度指數 (temperature-humidity index, THI ＝ 9/5 × T＋32－0.55 × (1－RH) × (9/5 × T－26)，其中 T＝ 溫度，℃，RH＝ 相對濕度

(relative humidity)，以小數點表示 (NOAA, 1976))。THI 為常用來表示牛隻熱緊迫程度的指標之一，參考 Armstrong (1994) 及 Hahn *et al*. (2009) 的報告，本次試驗以 THI ≤ 72, 72 < THI ≤ 78, 78 < THI ≤ 84, 及 > 84 區分方式分別表示牛隻處於舒適、輕度熱緊迫、中度熱緊迫與嚴重熱緊迫。試驗期間每週一與週五，依照牛舍溫濕度計的設置點，於 8:30, 13:30, 與 16:30，分別在 TMR 放置區、牛隻站立採食區與牛床間走道，約 1.5 m 牛背高度處測定風速 (Hot wire anemometer)，並記錄當時風扇開啟數目。

4.3.4 泌乳牛生理反應

每期試驗中重複兩天，於 03:00 與 13:00 分別以碼錶計算三組牛隻 2 次各 30 sec 的腹部起伏次數，為呼吸次數；同時間也以紅外線感測器 (infrared thermometer) 測定牛隻頸側及背側中央部位的皮膚溫度，測定距離約 1 m，感應 5 - 10 sec 可穩定顯示。以陰道溫度代表體內溫度，以酒精等多次徹底清洗 CIDR (control internal drug release) 內的助孕素 (progesterone, P4)，將 12 組 HOBO® water temp pro (Onset computer Corporation, Bourne, MA. USA) 分別置入空白 CIDR 中，於每期試驗正式期間分三批固定於牛隻陰道內 24 h，每分鐘測定記錄溫度一次，平均每 15 分鐘為一讀點。

每期試驗中重複兩天，於 13:00 以無抗凝劑之採血針 (Monovette®) 自牛隻頸靜脈採血，靜置 30 分鐘後以 2,500 rpm 離心 15 分鐘取血清，以血液自動分析儀 (Data Pro Plus random access clinical analyzer, ThermoTrace, Australia) 分析白蛋白 (albumin, Alb)、總蛋白(total protein, TP)、鈣 (Ca)、磷 (P)、葡萄糖 (glucose, Glu)、膽固醇 (cholesterol, Chol)、尿素氮 (blood urea nitrogen, BUN)、麩胺酸草酸醋酸轉氨酶 (aspartate aminotransferase, AST)、麩胺酸丙酸轉氨酶 (alanine aminotransferase, ALT)、鹼性磷酸酶 (alkaline phosphatase, ALP) 與乳酸脫氫酶 (LDH) 等血清生化值。同時，另以血液氣體採血針 (Blood Gas Monovette®) 自牛隻頸靜脈採血，保存於冰槽中，儘速以血液氣體測定儀 (pH/Blood Gas Analyzer, Instrumentation Laboratory, Model 16200-06, Italy) 分析全血 pH、氧分壓 (pO_2) 及二氧化碳分壓 (pCO_2)。

4.3.5 泌乳牛採食、瘤胃消化與泌乳性能

每日記錄三組 TMR 提供量、下午餵飼前剩餘量與牛隻頭數。每期正式期間採集兩次 TMR 原料、10 天的 TMR 與三組剩料，所有樣品保存於 -20℃，試驗結束

後以 55℃ 烘乾 48 小時，熱秤計算各組牛隻的乾物質採食量 (dry matter intake, DMI)。將各個別樣品混合成一個，進行粉碎與組成分析。每期以錄影記錄 10 日的牛隻活動，並選擇兩日進行每 10 分鐘牛群的採食活動比例 (採食頭數/總頭數 × 100%) 與躺下休息比例的計算。每期正式期間內進行連續 48 h 的瘤胃消化追蹤，採集各組內瘤胃開窗泌乳牛的瘤胃腹囊內容物，採集時間分別為 7:00 (0 h, 餵飼前), 9:00, 11:00, 13:00, 15:00 (8 h, 餵飼與擠乳前), 18:00, 20:00, 22:00, 0:00, 2:30, 與 5:00 (22 h, 擠乳前)。瘤胃內容物經紗布過濾後立即測定 pH，並以 50% 硫酸酸化 (1:50 v/v) 保存於 -20℃，以備氣相層析儀/火燄離子偵測器 (GC/FID, Varian CP-3800, Walnut Greek, CA) 分析揮發性脂肪酸 (Volatile fatty acid, VFA)，以光電比色計呈色法分析氨態氮 (NH_3-N) 濃度。每日記錄個別牛隻泌乳量。每期正式期採集兩次個別牛 a.m.-p.m. 乳樣，混合後分析乳成分、尿素氮及體細胞數等 (CombiFOSS^{TM} 5000, FOSS Analytical A/X, Slangerupgade, DK)。

4.3.6 統計分析

試驗相關氣候環境資料，以 Mean ± SD 方式紀錄。牛隻呼吸數、體溫、血液氣體、血清生化值、瘤胃消化產物、體重變化、乳量、乳成分與產量等，以個別牛資料進行統計分析；DMI 與採食活動等資料以組為單位進行分析，分析方法採用 SAS (2003) 統計軟體一般線性模式 (General linear model, GLM) 的拉丁設計分析，並以最小均方均值 (least squares means, LSM) 比較牛舍處理效應。本次試驗的顯著差異水準訂為 5%，若有明顯差異趨勢時 (P = 10%左右)，亦在相關表格中列出 P 值以為參考。

4.4 結果與討論

4.4.1 牛舍氣候環境

2006 年試驗期間牛舍環境模式與 2005 年第一代水簾牛舍試驗趨勢相同 (蕭等, 2009a)，水簾兩組在降低日間舍溫與 THI 的效果上優於傳統牛舍，但如預期的，水簾兩組全日相對濕度都維持在 96% 以上 (圖 4.1)。在氣溫方面，水簾兩組可以完全避免舍內溫度超過 30℃，但 Fan+SP 組一日內還有 4.5 h 的時間舍溫高過 30℃。水簾、WP+SP 兩組可以將舍內最高溫自 Fan+SP 牛舍的 31.5℃分別降低 3.7℃與 3.1℃，這個幅度與 Smith *et al*. (2006a) 報告的 3.1℃相近。乳牛最高臨界溫度推薦在 25℃到 26℃ (Berman *et al*., 1985)，水簾牛舍兩組平均可增加 35% 的 ＜26℃的

涼爽時間，相當於 4.2 h (16.2 h *vs*. 12.0 h)。在濕度方面，Fan+SP barn 的 RH 隨日間大氣溫度升高而降低，最低降到 68.7%，但夜間也回升趨近 100%， Fan+SP 牛舍平均每日有 69%的時間 (16.5 h) 相對濕度近 100%。THI 測定結果顯示，3 種牛舍的降溫都無法提供牛隻舒適的生活環境 (≤ 72 都為 0 小時)，牛隻一直處於輕度 (夜間，72 ≤ THI < 78) 到中度熱緊迫中 (日間，78 ≤ THI < 84)。水簾牛舍兩組可減少 38% (4.2 h) 牛隻曝露於中度熱緊迫的時間 (13 h, 8.5 h, 與 9.0 h)，並將一日 THI 平均值自 Fan+SP 的 79.0 拉低 1.8 與 1.4 單位 (表 4.2)，這個現象與 Smith *et al*. (2006a) 所述蒸發散熱隧道式牛舍可降低 84% 牛隻曝露於中度熱緊迫 (THI > 80) 的結論一致。除了日變化外，2006 年試驗於 8 月底到 10 月底進行，期間每日 THI 平均值分佈於 73 到 83 範圍 (圖 4.2)，並隨冬季的來臨與多次小颱風的影響而下降。在風速方面，試驗期間水簾牛舍大部分的日間都有 14 台抽風扇啟動，在全滿飼養下，水簾牛舍組日間平均風速為 2.38 m/s (表 4.3)，換算舍內每分鐘可換氣 2.8 次，WP+SP 牛舍組在牛舍入氣面第三欄位置，平均風速降低為 2.05 m/s，每分鐘可換氣 2.4 次，兩組高於 2005 年的 1.66 m/s 風速與每分鐘 2.0 次的換氣。水簾牛舍夜間溫度多低於 26℃，因此主要啟動 6 臺風扇來提供新鮮空氣，推算夜間風速為 1.17 m/s，每分鐘換氣僅僅 1.4 次。研究報告指出，在潮濕地區，乳牛體表濕透後最佳排熱所需要的風速為 2.9 – 4.0 m/s (Chastain and Turner, 1994)，2006 年增加風扇後，日間風速仍未達推薦的 2.9 m/s，夜間就更低了。

水簾牛舍藉由水降低入氣溫度，也帶來無法避免的高濕度問題。相對濕度影響牛隻舒適的臨界氣溫，相對濕度較低時，舒適氣溫可以為 27℃；相對濕度高時則降低到 22℃氣溫，牛隻即開始感受到熱緊迫 (Armstrong, 1994; West, 2003)；同時高濕度會使高溫的嚴重性更形惡化，在氣溫 24℃到 38℃範圍時，增加相對濕度就增加乳牛直腸溫與呼吸速度，其一原因是低溫時空氣水分含量少，而高溫空氣中含有大量水分 (Kibler and Brody, 1953)。相對濕度由 30%提高到 90%時，排汗速率由 500 g $H_2O/(m^2h)$ 降低至 60 g $H_2O/(m^2h)$ (Maia *et al*., 2005b)。高濕度問題可藉由足夠的風速來舒緩，當經過牛隻體表的風速由 0.2 m/s 提高到 0.9 m/s 時，排汗速率可由 75 g $H_2O/(m^2h)$ 提高到 350 g $H_2O/(m^2h)$ (Hillman *et al*., 2001)；而當噴霧降溫所配合的風速不夠時，微細水霧在牛隻體表毛髮上形成一層絕緣障礙，反而影響熱的蒸發排散 (Hahn, 1985)，2005 年水簾風速不足應是造成牛隻負面表現的主因。

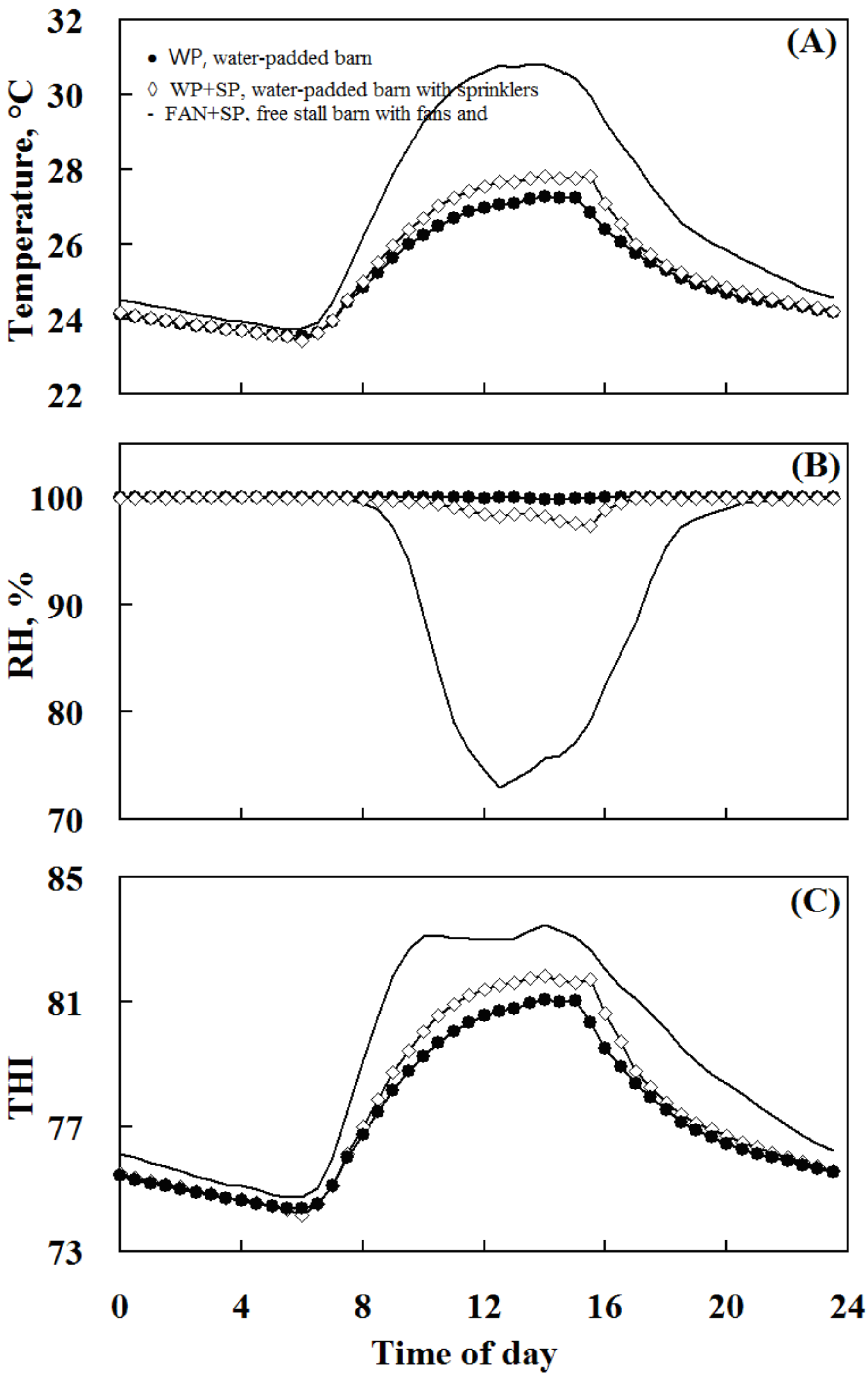

圖 4.1　2006 年夏季水簾牛舍評估試驗期間水簾牛舍、水簾+噴水牛舍及一般牛舍中的溫度、相對濕度與 THI 日變化。

Figure 4.1　Diurnal temperature (A), relative humidity (RH, B) and temperature humidity index (THI, C) change in the WP barn, WP+SP barn, and Fan+SP barn from Aug. to Oct. in 2006 in Taiwan.

表 4.2 高濕地區水簾牛舍紓解荷蘭泌乳牛熱緊迫試驗的環境參數 [1]

Table 4.2 Environmental profiles during the heat stress alleviation experiment for Holstein lactating cows by water-padded barns in humid summer of Taiwan in 2006[1]

Profiles[3]		Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]
No. of days observed		63	63	63
Temp, ℃	Mean	26.7 ± 1.0[4]	25.1 ± 1.1	25.4 ± 1.0
	Maximum	31.5 ± 1.1	27.8 ± 1.4	28.4 ± 1.2
	Minimum	23.5 ± 1.4	23.4 ± 1.1	23.3 ± 1.2
RH, %	Mean	92.9 ± 4.5	99.99 ± 0.1	99.5 ± 1.0
	Maximum	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0
	Minimum	68.7 ± 2.2	99.7 ± 1.7	96.1 ± 6.2
THI	Mean	79.0 ± 2.1	77.2 ± 1.9	77.6 ± 1.9
	Maximum	84.5 ± 2.6	82.0 ± 2.4	82.8 ± 2.4
	Minimum	74.4 ± 2.6	74.0 ± 2.0	74.0 ± 2.1

[1] Temperature and relative humidity were recorded every 30 min by HOBO Pro RH/Temp recorders (Onset Computer Corporation, MA, USA) in three barns from Aug. to Oct. in 2006. Mean data were calculated from 48 records each day and maximum and minimum data were the extreme data from each day.

[2] Fan+SP barn: Free stall barn with fans and sprinklers (control), WP barn: water-padding barn, WP+SP barn: water-padding barn with sprinklers.

[3] Temp: temperature, RH: relative humidity, THI: temperature-humidity index, $THI = 9/5 \times T + 32 - 0.55 \times (1 - RH) \times (9/5 \times T - 26)$, that T represents temperature in ℃ and RH in decimal (NOAA, 1976).

[4] Mean ± SD.

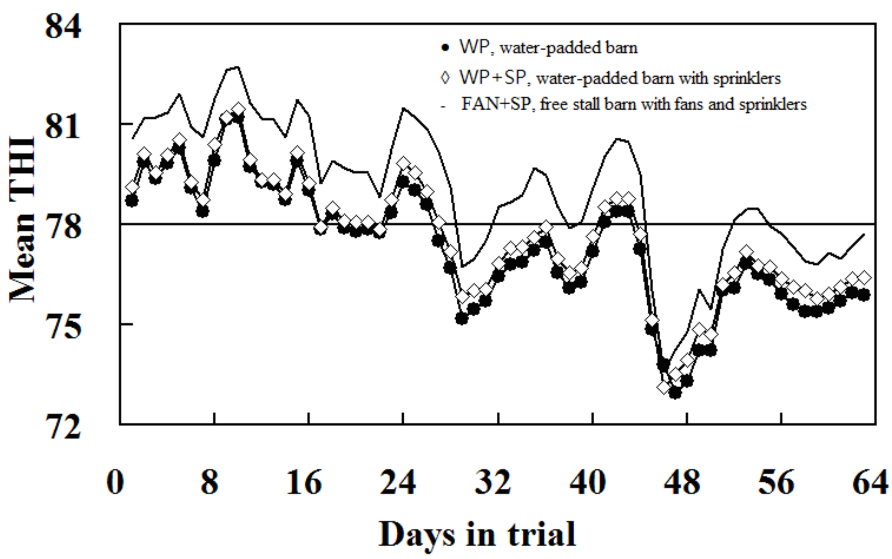

圖 4.2　2006 年夏季水簾牛舍評估試驗期間一般牛舍、水簾牛舍及水簾+噴水牛舍日平均 THI 變化。

Figure 4.2　Daily mean temperature humidity index (THI) in the WP barn, WP+SP barn, and Fan+SP barn from Aug. to Oct., 2006 in Taiwan.

表 4.3 高濕地區水簾牛舍紓解荷蘭泌乳牛熱緊迫試驗的畜舍風速 [1]

Table 4.3　Air velocity (m/s) in the water-padding barns during the heat stress alleviation experiment for Holstein lactating cows in humid summer in Taiwan[1]

Time	Days measured	Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]
08:30	15	1.18 ± 0.11[3]	2.22 ± 0.60	1.80 ± 0.49
13:30	16	1.23 ± 0.14	2.57 ± 0.27	2.23 ± 0.22
16:30	16	1.29 ± 0.11	2.34 ± 0.37	2.13 ± 0.40

[1] Air velocity was measured (Hot wire anemometer) every Monday and Friday in three fully occupied barns from Aug. to Oct. in 2006. Measurements were taken at three daytime points from the front and end sites of each group pen and from the feed alley, intake line and the free stall at 1.5 m elevation.

[2] WP barn: water-padded barn, WP+SP barn: water-padded barn with sprinklers, Fan+SP barn: Free stall barn with fans and sprinklers (control).

[3] Mean ± SD.

4.4.2 泌乳牛生理反應

4.4.2.1 呼吸速度與體溫

隨著氣溫的增加，牛隻散熱方式自非蒸發 (non-evaporative) 的對流 (convection)、傳導 (conduction) 與輻射 (radiation)，轉換成蒸發式的流汗 (sweating) 與喘氣 (panting) (Kibler and Brody, 1953)。氣溫達 19℃時牛隻呼吸次數開始增加，氣溫達 25℃時開始排汗 (Hahn *et al*., 1997; Maia *et al*., 2005a,b)。氣溫高於中溫帶後，牛隻呼吸速度 (respiration rate) 與氣溫成高度正相關 (Hahn *et al*., 1997)；在熱緊迫狀況下，牛隻體表溫度與呼吸速度有很高相關，同時體表溫度也可表現牛隻週遭的微環境 (Collier *et al*., 2006)。

試驗期間有四頭牛隻因生病或乾乳而離開。水簾兩組牛隻的呼吸次數在清晨 3 a.m.時高於 Fan+SP 組牛隻，分別為每分鐘 53 與 42 次 (P < .001)；到下午最熱時段 1 p.m.時，三組牛隻呼吸次數都高且相近，平均為每分鐘 54 次 (圖 4.3 (A))，Fan+SP 牛舍牛隻的呼吸速度隨氣溫增加而增加，下午增加 12 次的呼吸次數，但水簾兩組牛隻全日呼吸速度都高，即使較涼爽的清晨也仍須喘氣。牛隻呼吸速度的模式與 2005 年一致，但較和緩 (蕭等, 2009a)。頸側或背側體表溫在清晨 3 點的趨勢與呼吸速度一致 (圖 4.3 (B, C))，水簾及水簾+噴水組牛隻高於傳統牛舍牛隻，三組背側溫分別為 28.92℃、29.27℃與 28.31℃ (P < .001)；牛隻體表溫隨氣溫上升而上升，以 Fan+SP 組上升幅度最大，下午炎熱 1 點時的體表溫，以傳統牛舍最高，水簾+噴水組其次，水簾組最低 (P < .001)，三組背側溫分別為 32.48℃、31.60℃與 31.04℃ (P < .001)。背側皮膚對環境溫度的敏感度較頸側皮膚為高。不論清晨或下午，牛隻呼吸次數都遠高於舒適時的 26 次到 35 次 (Reece, 1993)，顯示三種牛舍環境都未能完全紓解牛隻熱緊迫如前牛舍環境測定結果。水簾牛舍夜間環境問題值得重視，三種牛舍在清晨時的溫度、RH 與 THI 都相近 (圖 4.1)，但水簾兩組牛隻的呼吸次數與體表溫顯著高於對照組，顯示還有其他因素影響著牛隻的熱負荷，風速顯然是一重要因素。水簾牛舍夜間風速較日間降低 50%，推算僅 1.17 m/s，遠低於 2.9 – 4.0 m/s 的推薦 (Chastain and Turner, 1994)，因此可能影響排汗功能 (Hillman *et al*., 2001)，而使牛隻須要藉由快速喘氣來排熱，因此在未來水簾牛舍的修正方向中，最低風扇啟動數的舍溫設定 26℃應予以適度降低，來提高夜間風速；另一推測的因素為畜舍型式，當環境變涼爽後，牛隻體熱可藉由體表輻射到環境中 (Hahn, 1994)，水簾牛舍的密閉型式是否限制體表熱的輻射排除，值得進一步探

討。

在體內溫度方面，三組泌乳牛陰道溫度的日變化非常有趣 (圖 4.4)，水簾組牛隻的陰道溫度持續高檔，全日分佈在 38.9 到 39.2℃範圍，主要變化為兩次擠乳後所帶來約 0.15℃的下降；在同一棟牛舍內的水簾+噴水組牛隻的反應完全不同，反而與 Fan+SP 組的趨勢一致，牛隻陰道溫度隨擠乳與噴水處理大幅降低，且以噴水降溫的效果更明確，陰道溫度降幅可以達到 0.4 到 0.6℃。這樣的結果闡明了噴水濕潤牛隻體表再吹乾的蒸發散熱是有效與經濟的牛隻降溫方法，Hillman *et al*. (2005) 報告牛隻在餵飼走道接受 17 分鐘噴水吹風中，陰道溫度以 -0.5℃/h 的速度下降，當噴水吹風處理延長為 64 分鐘，陰道溫度更是以-1.02℃的速度下降。Berman (2010) 也報告，在連續七次噴水吹風處理中，有潤濕皮膚的降溫速度較乾燥皮膚處為快，幅度也較高。更進一步，本次試驗也解釋了相關的疑慮，就是即使在相對濕度近 100%的高濕環境下，噴水吹風仍然可以有效幫助牛隻體熱的排除，這樣的推薦也在 Brouk *et al*. (2001) 報告中提出，其認為蒸發降溫、隧道抽風與噴水的聯合使用可以有效降低牛隻呼吸次數與體溫。本次試驗三組牛隻陰道溫度的最高溫都達到 39.53℃，日平均與最低溫趨勢相同，都以水簾組高於另二組 ($P < .01, .001$)，水簾組最高溫與最低溫的差距僅 1.12℃，低於另二組 1.43 及 1.45℃的降低幅度 (表 4.3)。

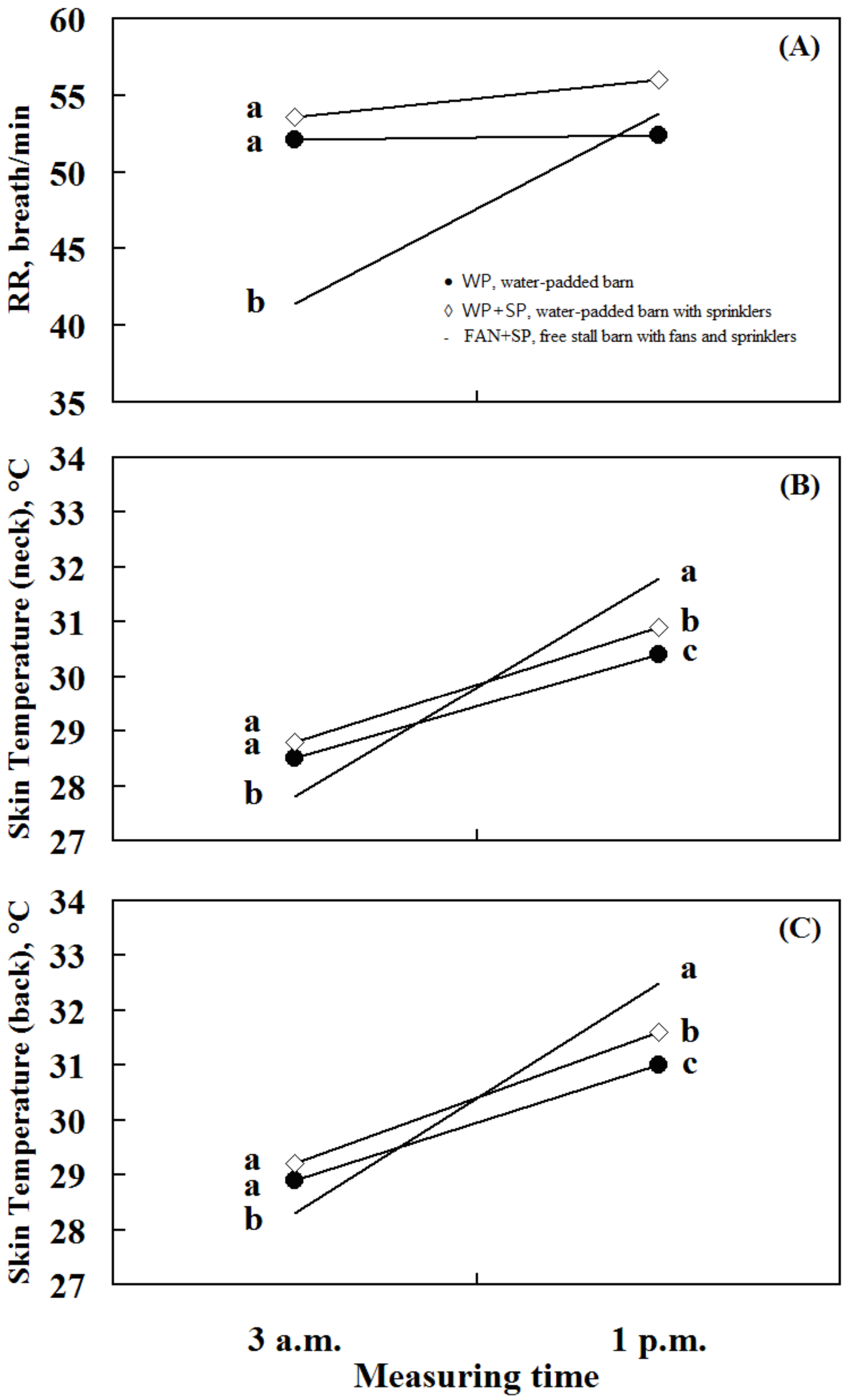

圖 4.3　高濕熱地區水簾牛舍環境對荷蘭泌乳牛呼吸次數與體表溫度之影響

Figure 4.3　The 3 a.m. and 1 p.m. respiration rates (RR) (A), skin temperature (T) of neck (B) and back (C) of lactating Holstein cows raised in the WP barn, WP+SP barn, and Fan+SP barn during the hot and humid Aug. to Oct., 2006 in Taiwan. Data point with different characters, a, b, and c, differ (*P* < 0.001).

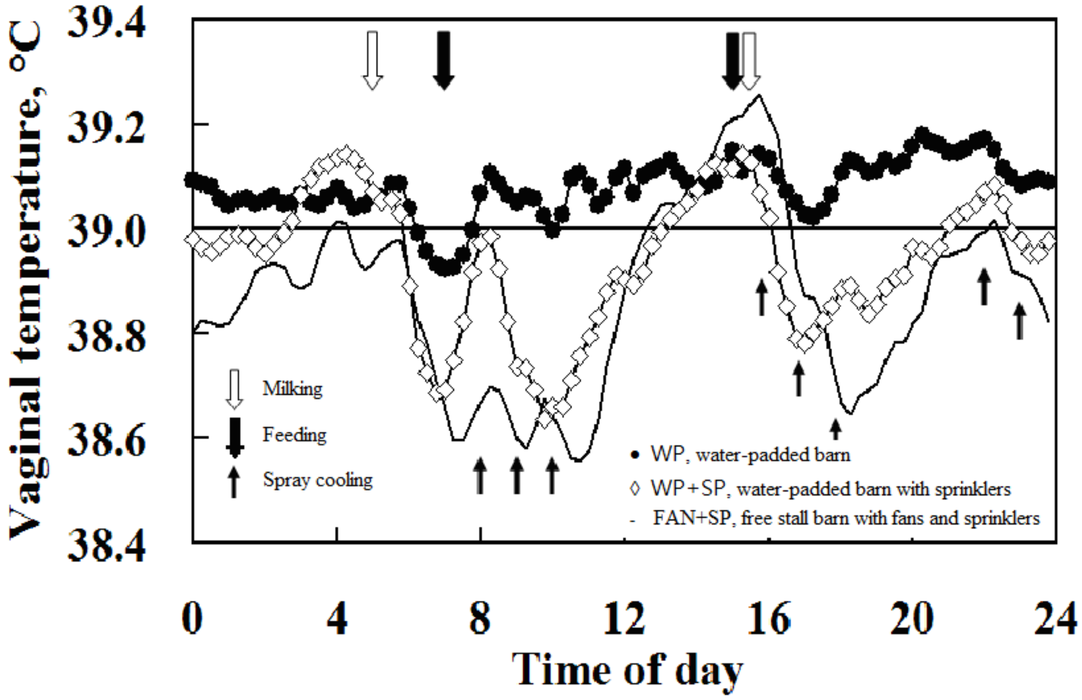

圖 4.4　高濕熱地區水簾牛舍環境對荷蘭泌乳牛陰道溫度日變化之影響。

Figure 4.4　Effect of water-padding barn environment on the diurnal vaginal temperature of Holstein lactating cows raised in the WP barn, WP+SP barn, and Fan+SP barn during the hot and humid Aug. to Oct., 2006 in Taiwan.

表 4.4　高濕熱地區水簾牛舍環境對荷蘭泌乳牛陰道溫度之影響 [1]

Table 4.4　Effect of water-padded barn environment on the diurnal vaginal temperature of Holstein lactating cows in humid summer in Taiwan in 2006[1]

Item	Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]	SEM[3]	Sig[3]
No. of cows measured	32	32	32		
Diurnal mean, ℃	38.87[b]	39.08[a]	38.94[b]	0.04	**
Highest value (H),[4] ℃	39.58	39.65	39.53	0.07	NS
Lowest value (L),[4] ℃	38.16[b]	38.53[a]	38.07[b]	0.06	***
H – L, ℃	1.43[a]	1.12[b]	1.45[a]	0.09	*

[a,b] Means within a row with different superscripts differ ($P < 0.05$).

[1] Vaginal temperatures were measured every 1 min by the HOBO water temp Pro data logger (Onset computer corporation, Bourne, MA. USA) that fixed in a blank control internal drug release (CIDR) device and inserted into cow's vagina 24 h.

[2] WP barn: water-padded barn; WP+SP barn: water-padded barn with sprinklers; Fan+SP barn: Free stall barn with fans and sprinklers (control).

[3] SEM: standard error of the mean; Sig: significance; NS: non-significant, $P > 0.05$; * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$.

[4] Mean data were analyzed from the daily averages of 32 cows each group and the highest and lowest values were the averages of daily extreme data for each cow.

4.4.2.2 血液氣體及生化值

熱緊迫環境影響牛隻體內酸鹼平衡 (West *et al*., 1992)。當熱負荷增加時，牛隻藉由快速喘氣來提高上呼吸道的蒸發散熱作用，但喘氣增加 CO_2 的排出，也造成呼吸性鹼毒症 (respiratory alkalosis) 現象，即血中 CO_2 分壓降低、HCO_3^- 濃度降低及血液 pH 上升 (Collier *et al*., 1982; Sanchez *et al*., 1994; Calamari *et al*., 2007)。在 2005 年試驗中，第一代水簾牛舍的高濕與低風速環境造成牛隻明顯的熱負荷，因此確實出現呼吸性鹼毒症現象 (蕭等, 2009a)；但 2006 年試驗就沒有這樣的趨勢，三組牛隻血液 CO_2 分壓相近，WP 組牛隻血液 pH 值反而有較低的趨勢 (P = 0.08) (表 4.4)，顯示水簾兩組牛舍環境的改善已有效紓緩牛隻的熱緊迫程度。Fan+SP 組牛隻血液 O_2 分壓高於水簾二組 (P < .05) 的原因則可能與牛舍型式有關。寒冷季節時，飼養於開放式牛舍 (open-shed barn) 牛隻的血液 O_2 分壓，高於

飼養於密閉牛舍牛隻，其原因可能來自空氣的流通程度 (Sabuncuoglu *et al*., 2008)。

血液生化值可做為熱緊迫指標 (Abeni *et al*., 2007; Calamari *et al*., 2007)。與血液氣體不同，2006 年 WP 與 Fan+SP 兩組牛隻各項血液生化值的反應趨勢與 2005 年一致，即兩組牛隻血清的白蛋白、BUN, Ca, Glucose, AST, 與 LDH 相近，WP 組的血清總蛋白質與磷較 Fan+SP 高，膽固醇、ALP 與 ALT 較 Fan+SP 低；而 WP+SP 組除了磷濃度降低與 Fan+SP 相近外，其餘都跟隨 WP 組的趨勢 (表 4.4)。

當氣溫由 18℃進入 32℃，血清蛋白質與尿素氮濃度有增高情形 (Koubková *et al*., 2002)，本次試驗水簾兩組牛隻血清總蛋白質增高，但白蛋白與 BUN 則與對照組相近。熱季造成荷蘭牛血漿中葡萄糖濃度、膽固醇濃度與鹼性磷酸酶 (alkaline phosphatase, ALP) 活性的降低 (Abeni *et al*., 2007; Calamari *et al*., 2007)，水簾兩組牛隻血清膽固醇濃度與鹼性磷酸酶活性低於對照組，但葡萄糖濃度與對照組相近。AST 與 ALT 參與蛋白質代謝過程中胺基的轉換，Koubková *et al*. (2002) 報告高產牛的 ALT 活性隨環境溫度增高而下降，水簾兩組牛隻的 ALT 活性低於對照組 ($P < .001$)，但 AST 活性則有高於對照組的趨勢 ($P = 0.10$)。牛隻血清鈣的濃度不受三組環境的影響，但水簾組牛隻血清磷濃度高於對照組，且在 2005 年也出現此現象 (蕭等, 2009a)，Sanchez *et al*. (1994) 指出熱緊迫會減少牛隻 50% 磷的吸收，可能因此增加了血清中的磷的滯留與減少細胞內 ALP 的合成原料，這個推論須要進一步證實，WP 組的血液測定結果符合這個推論，而 WP+SP 組牛隻血清磷濃度未增加，同時 ALP 活性介於另兩組之間，似乎表示 WP+SP 組牛隻的熱緊迫程度低於 WP 組牛隻。綜合本次血清生化值結果，尚無法一致性的釐清三種牛舍環境對紓解泌乳牛熱緊迫的效果。

表 4.5　高濕熱地區水簾牛舍環境對荷蘭泌乳牛血液氣體分壓及血清生化值之影響

Table 4.5　Effect of water-padded barn environment on the blood gases and serum biochemical metabolites of Holstein lactating cows in humid summer in Taiwan in 2006[1]

Item	Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]	SEM[3]	Sig[3] (*P* value)
No. of cows measured	32	32	32		
Blood pH	7.405	7.397	7.404	0.003	(0.08)
pCO_2,[2] mmHg	42.3	42.8	42.6	0.4	NS
pO_2,[2] mmHg	31.5[a]	30.5[b]	30.4[b]	0.3	*
Total protein, g/L	69.5[b]	70.6[ab]	71.6[a]	0.5	*
Albumin, μmol/L	0.49	0.49	0.49	0.01	NS
BUN, mmol/L	7.28	7.56	7.40	0.11	NS
Ca, mmol/L	2.16	2.18	2.18	0.02	NS
P, mmol/L	1.94[b]	2.08[a]	1.95[b]	0.03	*
Glucose, mmol/L	2.34	2.28	2.34	0.05	NS
Cholesterol, mmol/L	6.47[a]	6.21[ab]	6.10[b]	0.09	*
ALP,[2] U/L	43.5[a]	38.8[b]	41.4[ab]	1.0	**
AST,[2] U/L	81.7	86.2	85.7	1.6	(0.10)
ALT,[2] U/L	42.9[a]	40.6[b]	41.5[b]	0.4	***
LDH,[2] U/L	672	690	693	19	NS

[a,b] Means within a row with different superscripts differ ($P < 0.05$).

[1] Blood samples of 32 cows each group were taken twice at 1 p.m. from jugular vein each period in a 3 x 3 latin square design.

[2] Fan+SP barn: Free stall barn with fans and sprinklers (control), WP barn: water-padding barn, WP+SP barn: water-padding barn with sprinklers, pCO_2: partial pressure of carbon dioxide, pO_2: partial pressure of oxygen, ALP: alkaline phosphatase, AST: aspartate aminotransferase, ALT: alanine aminotransferase, LDH: lactate dehydrogenase.

[3] SEM: standard error of the mean; Sig: significance; NS: non-significant, $P > 0.05$; * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$, P value around 0.10 was also listed.

4.4.2.3 泌乳牛採食活動、瘤胃消化與泌乳性能

牛隻飼糧組成與設定值相近，牛隻採食 50%芻料 (乾基)、24%副產物與 26%穀類精料的完全混合日糧 (totally mixed ration, TMR)，飼糧組成為 DM 39.0%、CP 16.5%、ADF 32.1%及 NDF 50.0% (乾基)。近年相關牛隻降溫方法的研究中，多以呼吸速度及體溫等生理反應為評估指標，本次採食活動、瘤胃消化與泌乳性能的評估相對較少。

4.4.2.3.1 採食活動

經錄影觀察與計算，牛隻在三種環境下的採食與躺臥時間沒有顯著差異，分別為每日 4.8 - 5.7 h 的採食及 11.5 - 12.3 h 的躺臥休息 (表 4.6)。牛隻舒適度研究推薦，泌乳牛每日須有 3 - 5 h 的採食與 12 – 14 h 的躺臥休息 (Grant, 2007)，本次試驗顯示在高溫高濕環境下，牛隻的採食時間會延長，而躺下休息時間則縮短，這個現象與熱緊迫時牛隻每餐採食量少但次數增加與熱會促使牛隻站立以增加排熱表面積的觀察是相符合的。三組牛隻的採食活動在兩次新鮮 TMR 餵飼後明顯增加 (圖 4.5)，尤其是下午餵飼後的 2.5 h 內，持續有 51%到 68%的牛隻進食 (表 4.6)，Fan+SP 組牛隻採食活動有高於水簾組牛隻的趨勢 (P = 0.11)，上午餵飼後的 2 h 內，持續有 43 到 54%的牛隻進食，其他時間的採食活動則多低於 25%，牛隻採食活動最少的時段為中午及午夜到清晨兩個時段，僅 6.3%到 12.6%。日間採食活動強度的趨勢，以風扇+噴水對照組較高，水簾組較低，水簾+噴水組居中。與 2005 年比較，第一代水簾牛舍環境顯著降低牛隻下午餵飼後 43%的採食活動 (35.7% *vs.* 62.1%, P < .05) (蕭等, 2009b)，經過增加風速與噴水處理的改善，2006 年水簾兩組的採食活動已明顯增加，尤其是水簾+噴水組，兩組下午主餐的採食活動分別達到對照組的 75% 與 91%。

4.4.2.3.2 瘤胃消化與泌乳性能

本次試驗提供三組牛隻相同飼糧，牛隻表現的採食活動模式相近，使泌乳牛瘤胃消化的表現大部分相近。Fan+SP 組、水簾組與水簾+噴水組牛隻瘤胃 pH 的日加權平均值相近，分別為 6.24, 6.12, 與 6.20 (圖 4.6，A)。瘤胃 pH 最高值平均 6.47，出現在上午 7 點餵飼前，最低值平均 5.90，約出現在下午餵飼後 5 個小時的 8 點。水簾組牛隻的瘤胃氨態氮最低濃度高於對照組 (11.7 *vs.* 8.0 mg%, P < .05)，因此其氨態氮日加權平均值有較 Fan+SP 組牛隻高的趨勢 (15.0 *vs.* 12.7 mg%, P = 0.06)，本次試驗氨態氮濃度分佈於 10 – 20 mg%，沒有很大的濃度變化 (圖 4.6，B)。瘤

胃 VFA 提供牛隻重要的能量來源，三種牛舍環境飼養下的牛隻瘤胃總 VFA 濃度與個別 VFA 莫耳比例都相近，瘤胃總 VFA 濃度分別為 110、112 與 104 m*M* (圖 4.6，C)。

對照組、水簾組與水簾+噴水組的環境並不影響牛隻體重的變化 (表 4.7)，但水簾兩組顯著促進牛隻的採食量 (18.8 *vs*. 18.5 kg, *P* < .05)，雖然每頭每天計算值只增加 0.3 kg，但可以達 5%顯著水準表示其高的可信度。水簾兩組環境的改善提升牛隻採食意願，有效促進採食量的增加，進一步促進乳量的增加，水簾組乳量已與對照組相近 (25.0 *vs*. 24.7 kg)，水簾+噴水組乳量更呈現高於對照組的趨勢 (25.4 *vs*. 24.7 kg, *P* = 0.10)。在乳成分方面，除了水簾+噴水組的乳蛋白質濃度顯著降低，原因尚待探討外，其餘乳脂肪、乳糖與乳總固形物濃度都相近；在乳房健康方面，減低熱緊迫可以降低生乳體細胞數，Smith *et al*. (2006b) 報告隧道蒸發降溫可降低 27%的生乳體細胞數，本次試驗也顯示水簾牛舍環境有改善乳房健康的趨勢，水簾與水簾+噴水兩組牛隻的生乳體細胞數分別較 Fan+SP 對照組牛隻降低 43% 與 54% (*P* = 0.13)。本次試驗結果雖未達到 Smith *et al*. (2006b) 每頭每天增加 11%採食量與 2.0 kg 乳量 (FCM) (3.5%FCM, 23.6 *vs*. 21.6 kg) 的幅度，但與 2005 年水簾組環境降低牛隻乾物質採食量 7.6% (17.0 *vs*. 18.4 kg) 及接續降低 10.1%乳量 (4% FCM, 23.1 *vs*. 25.7 kg, *P* < .001) (蕭等, 2009b) 的負面結果比較，2006 年風速與噴水的改善已使水簾牛舍呈現可能的經濟效益，這個結果使得在濕熱地區應用水簾+噴水牛舍來紓解泌乳牛熱緊迫的可行性已大幅提高。

表 4.6　高濕熱地區水簾牛舍環境對荷蘭泌乳牛採食與躺臥活動之影響 [1]

Table 4.6　Effect of water-padded barn environment on the intake and lying activities of Holstein lactating cows in humid summer of Taiwan in 2006[1]

Time segment	Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]	SEM[3]	Sig[3] (*P* value)
No. of observations	3	3	3		
Time in lying, h/d	12.2	11.5	12.3	0.3	NS
Time in eating, h/d	5.7	4.8	5.1	0.2	NS
	-------- Percentage of cows in eating --------				
7:30 – 9:30 (a.m. feeding)	53.9	42.9	47.7	6.4	NS
9:30 – 11:30	23.6	21.9	24.8	0.5	(0.10)
11:30 – 14:30	12.6^{a}	6.3^{b}	8.5^{ab}	0.7	*
15:00 – 17:30 (p.m. feeding)	67.7	50.7	61.3	3.1	(0.11)
17:30 – 21:00	21.0	22.1	23.8	2.2	NS
21:00 – 0:00	17.0	19.2	20.1	2.5	NS
0:00 – 5:00	9.8	11.2	7.2	0.8	NS
5:00 – 7:30	22.2	13.4	14.8	3.9	NS

[a,b] Means within a row with different superscripts differ ($P < 0.05$).

[1] A total of 36 cows were randomly assigned into three barn treatments in a 3 x 3 latin square design and group-fed. Two 24-h cow activity each period were recorded by video and counted every 10 min. Number of cows eating was calculated as the percentage of each group.

[2] Fan+SP barn: Free stall barn with fans and sprinklers (control), WP barn: water-padded barn, WP+SP barn: water-padded barn with sprinklers.

[3] SEM: standard error of the mean; Sig: significance; NS: non-significant, $P > 0.05$; * $P < 0.05$; *P* values around 0.10 was also listed.

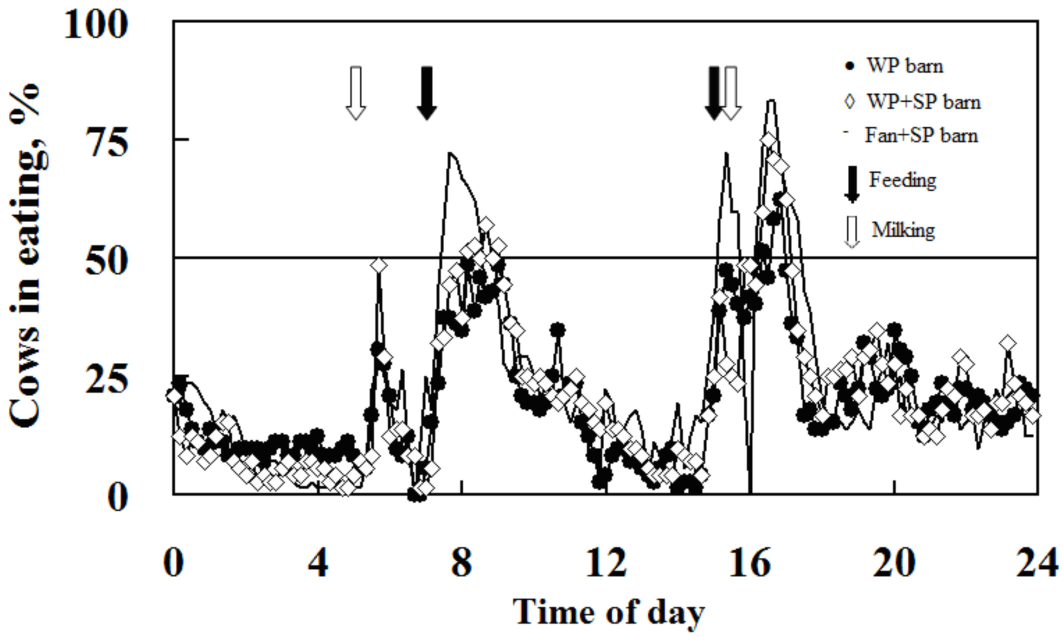

圖 4.5　高濕熱地區水簾牛舍環境對荷蘭泌乳牛採食活動之影響。

Figure 4.5　Effect of water-padded barn environment on the intake activity of Holstein lactating cows raised in the WP barn, WP+SP barn, and Fan+SP barn during the hot and humid Aug. to Oct. in 2006 in Taiwan.

表 4.7　高濕熱地區水簾牛舍環境對荷蘭乳牛泌乳性能之影響 [1]

Table 4.7　Effect of water-padded barn environment on the lactation performance of Holstein cows in humid summer of Taiwan in 2006[1]

Item	Fan+SP barn[2]	WP barn[2]	WP+SP barn[2]	SEM[3]	Sig[3] (P value)
No. of observations	3	3	3		
DMI, kg	18.5[b]	18.8[a]	18.8[a]	0.03	*
No. of cows observed	32	32	32		
Initial BW,[2] kg	546	549	549	2	NS
BW gain, kg/d	0.40	0.23	0.32	0.10	NS
Milk yield, kg/d	24.7	25.0	25.4	0.2	(0.10)
4% FCM, kg/d	24.9	25.1	25.4	0.3	NS
Milk fat, %	4.06	4.05	4.02	0.05	NS
Milk protein, %	3.18[a]	3.18[a]	3.11[b]	0.02	*
Milk lactose, %	4.74	4.73	4.75	0.02	NS
Milk total solid, %	12.67	12.67	12.58	0.05	NS
SCC, *10^4/mL	127	73	58	25	(0.13)

[a,b] Means within a row with different superscripts differ ($P < 0.05$).

[1] A total of 36 cows were randomly assigned into three barn treatments in a 3 x 3 latin square design and group-fed. Milk yields were recorded daily and three a.m.-p.m. milk were sampled for composition analyses each period. Statistically analyzed milk data came from 32 cows that went through the trial.

[2] Fan+SP barn: Free stall barn with fans and sprinklers (control), WP barn: water-padded barn, WP+SP barn: water-padded barn with sprinklers.

[3] SEM: standard error of the mean; Sig: significance; NS: non-significant, $P > 0.05$; * $P < 0.05$; P value around 0.10 was also listed.

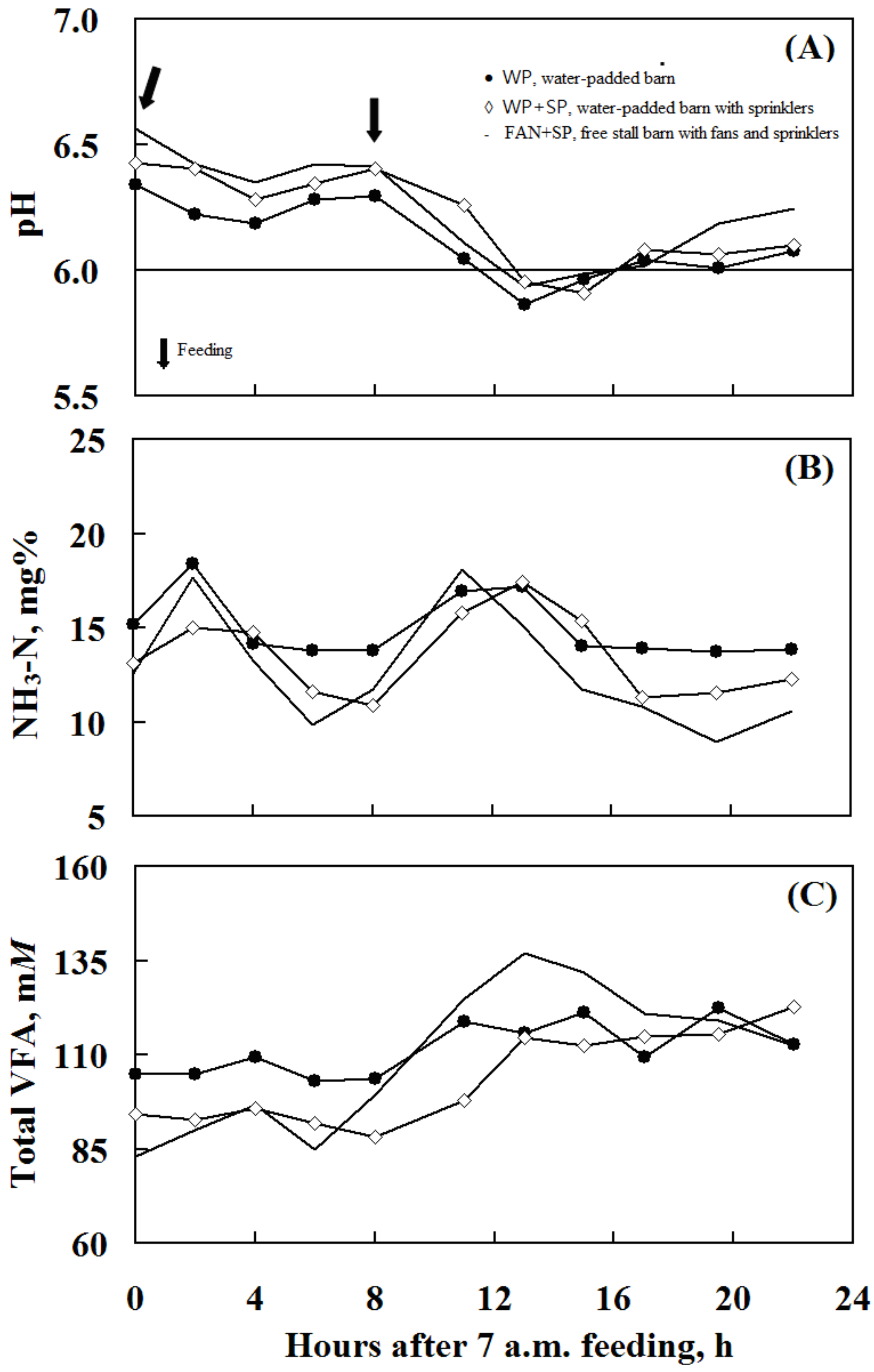

圖 4.6　高濕熱地區水簾牛舍環境對荷蘭泌乳牛瘤胃消化之影響

Figure 4.6　Effect of water-padded barn environment on the diurnal rumen pH, NH_3-N and volatile fatty acids (VFA) concentrations of three rumen-cannulated Holstein lactating cows raised in the WP barn, WP+SP barn, and Fan+SP barn during the hot and humid Aug. to Oct. in 2006 in Taiwan.

4.5 結論

本次試驗評估結果顯示，水簾+噴水牛舍在紓解乳牛熱緊迫上有其潛力與期望，水簾牛舍降低日間舍溫與 THI 的能力高於傳統自由牛舍，但有高濕度問題，可藉由足夠的風速與噴水處理進行改善。水簾牛舍日間風速自每秒 1.66 m 提高到 2.05 m (每分鐘換氣自 2 次增加到 2.4 次)，並配合餵飼走道的噴水處理，牛隻乳量已較噴水吹風自由牛舍牛隻增加近 3% (25.4 kg *vs.* 24.7 kg)，目前本研究群持續進行水簾牛舍設計的修改，關鍵點在於風速的增加，尤其是夜間時段。

第五章 以水簾牛舍改善荷蘭種泌乳牛熱季繁殖效率可行性評估

5.1 中文摘要

高濕高溫所造成的熱緊迫環境，嚴重的降低泌乳牛夏季繁殖效率，隧道式抽風蒸發冷卻牛舍 (簡稱水簾牛舍) 是一種在評估中的降溫牛舍型式，本研究在探討水簾牛舍對改善熱季泌乳牛繁殖性能之可行性。試驗分三階段進行，分別為水簾牛舍對泌乳牛血中助孕素濃度影響、對標的配種下泌乳牛繁殖效率之影響與對長期飼養於水簾牛舍泌乳牛繁殖效率之影響。2005 年熱季，以未懷孕泌乳牛 12 頭，分別飼養於一般牛舍與水簾牛舍 (換氣速度 2 次/min)，進行同期化發情處理，並於前列腺素注射日、發情前、配種日與配種後第 7 日採集尾靜脈血樣，分析血清中助孕素濃度，結果顯示二處裡間助孕素濃度並無顯著差異。2007 年熱季，將 40 頭泌乳牛逢機分為二組，分別飼養於一般牛舍與水簾牛舍 (換氣速度 3.2 次/min + 噴水)。試驗為期 90 天，前 14 天為適應期，適應期後開始間隔 14 日兩次前列腺素注射的發情同期化處理。試驗結果顯示，熱季期間試驗牛隻不論在一般牛舍或水簾牛舍，對於標的配種的反應皆不理想，全期試驗發情配種頭數分別為 29 頭次與 23 頭次，每次人工授精受孕率分別為 20.7%與 17.4%，全期懷孕率分別為 30.0%與 21.1%，具噴水處理的水簾牛舍未能改善熱季泌乳牛繁殖性能。於 2008 - 2010 連續三年期間，調查泌乳牛飼養於一般牛舍或水簾牛舍 (換氣速度 3.2 次/min + 噴水) 對繁殖效率之影響。結果顯示，懷孕率在熱季 (5 - 10 月) 分別為 29.0%與 26.4%，全年分別為 40.2%與 36.3%，並無顯著性差異。綜上結果，熱季泌乳牛飼養於有噴水處理的水簾牛舍，並未能有效改善熱季繁殖性能，可能是水簾牛舍全日高相對濕度與夜間風速不足，因此無法有效紓解體內的熱積聚所致，未來研究將著重於降低水簾牛舍相對濕度與增加夜間風速。

5.2 緒言

由於國人鮮乳消費型態，夏季鮮乳需求較高冬季則銳減，這與來自溫帶的荷蘭種乳牛不耐熱的生理特性相牴觸，因此會造成夏乳不足冬乳過剩的現象。為鼓勵夏乳的生產，國內牛乳生產採配額制，各乳廠普遍採用夏期＋暖期 67% 的交乳量，來計算冬期 33% 的收乳量，冬期多出來的乳量以外調乳或剩餘乳價格收購，而夏期乳價高於冬期乳價近 7.5 元/kg。酪農為配額與乳價，只能採取季節配種與

產期調節來因應，然而在炎熱夏季的熱緊迫環境下，乳牛的繁殖效率是非常低的，如何改善牛隻繁殖性能是一大挑戰。有鑒於水簾畜舍在豬與家禽生產上得到正面的反應，是否可以利用水簾畜舍在炎熱夏季改善乳牛繁殖效率，值得探討。

熱緊迫影響牛隻血液中助孕素濃度，在研究報告中有增加助孕素濃度 (Trout *et al*., 1998; Abilay *et al*., 1975)，降低助孕素濃度 (Ronchi *et al*., 2001) 與不影響助孕素濃度 (Roth *et al*., 2000; Guzeloglu *et al*., 2001) 等結果出現。這些不同的結果可能是由於不同型態的熱緊迫 (長期或短期)，不同的生殖週期時期或不同乾物質採食模式所造成 (Khodaei-Motlagh *et al*., 2011)。若熱緊迫造成血液中助孕素濃度低落，黃體期低的助孕素濃度會影響隨後濾泡的發育，造成卵子成熟不正常與胚早期死亡 (Ahmad *et al*., 1995)；在懷孕早期，低的助孕素濃度會致使胚著床失敗 (Mann *et al*., 1999)。

本試驗經由兩種不同型式的牛舍，以配種前後血中助孕素濃度做為指標，探討水簾牛舍紓解泌乳牛熱緊迫的可行性，再透過標的配種的繁殖管理模式，進行比較試驗，最後調查水簾牛舍三年田間測試結果，評估水簾牛舍對繁殖效率之影響。

5.3 材料與方法

5.3.1 水簾牛舍對熱季泌乳牛血中助孕素濃度之影響

試驗牛隻為分娩後 60 - 150 日之未孕泌乳牛 12 頭，逢機分成兩組，分別飼養於水簾牛舍 (n = 5) 與一般牛舍 (n = 7)。水簾牛舍與一般牛舍環境設定及牛隻飼養管理同於前 2.3 節之材料方法所述。牛隻經過 14 日的適應期飼養後，肌肉注射前列腺素 2 mL (prostaglandin, PG, Estrumate, Essex Animal Health Friesoythe, Friesoythe, Germany)，進行同期化發情處理，並於 PG 注射日、發情前、發情配種日與配種後第 7 日，分別自尾靜脈採血，分離血清後以免疫分析系統 (Access Immunoassay System, Beckmen) 分析血清中助孕素濃度。

5.3.2 水簾牛舍對熱季泌乳牛標的配種計畫效果之影響

5.3.2.1 試驗動物管理

選擇乳量 19 kg 以上泌乳牛 40 頭，依照乳量、胎次、泌乳天數與體重等逢機均分為二組，分別飼養於一般牛舍與水簾牛舍兩區，泌乳牛每日於 5:00 與 15:15 擠乳兩次，逐日電腦記錄個別乳量。兩種牛舍設置相同的頸夾餵飼走道、牛床及

不銹鋼水槽，糞尿處理採定時刮糞處理，二牛舍皆採滿額飼養，以符合實際狀況。牛群按月過磅並藥浴。

試驗牛群任食同樣的完全混合日糧，於 7:00 及 14:00 分別配製新鮮飼糧 1/3 與 2/3 量。每日下午餵料前收集剩料，記錄重量，並依據調整總配製量及各組下料量，使剩餘量約為其提供量的 5%。飼糧提供 1.14 倍乳量的營養需要量，即 26 kg 泌乳營養需要量 (NRC 2001)。飼糧組成包括青貯玉米料 30 kg、盤固乾草 2.5 kg、苜蓿乾草 2.5 kg、啤酒粕+磨碎玉米青貯料 12 kg、黃豆殼粒 2.5 kg 及精料 3.2 kg (餵飼基)。飼糧計算組成為乾物量 20.3 kg/頭/天、乾物質 38.5%、粗蛋白質 15%、泌乳淨能 1.5 Mcal/kg、中洗纖維 48%、酸洗纖維 32%、非結構性碳水化合物 30% (100 – 粗蛋白質 – 中洗纖維 – 粗灰分 – 粗脂肪)、鈣 0.64%、磷 0.36%及陰陽離離子差 (DCAD) 210 meq/kg DM。配方中精料每公噸粒料包括磨碎玉米 300 kg、大豆粕 320 kg、麩皮 200 kg、糖蜜 50 kg、碳酸鈣 60 kg、磷酸氫鈣 10 kg、鹽 30 kg、牛維生素預混物 1.5 kg 及牛礦物質預混物 1.5 kg (餵飼基)。

5.3.2.2 試驗設計與標的配種計畫

採二處理單因子設計，試驗為期 90 天，自 2007 年 7 月 1 日至 9 月 30 日，前 14 天為適應期，適應期後開始標的配種計畫。試驗處理為二種牛舍環境，分別為對照組的傳統挑高太子樓自由牛舍 (一般牛舍組) 與水簾牛舍+噴水處理，水簾牛舍為單排頸夾之自由牛舍，可容納約 48 頭成熟母牛。一般牛舍與水簾+噴水組的噴水降溫措施，於早上 8:00、9:00、10:00、15:50、16:50、17:50、22:00 與 23:00 共八次進行，每次 30 分鐘六循環，每循環五分鐘內包括噴水一分鐘，停水吹乾四分鐘。

試驗牛隻經分組後，進入處理牛舍飼養為期 14 日適應期後，給與前列腺素 2 mL 注射進行發情同期化，並觀察發情 4 日，牛隻若穩定發情則給予人工授精；未發情配種牛隻於 14 日後給與第二劑前列腺素注射，並再觀察發情 4 日，牛隻若穩定發情則給予人工授精；對二次前列腺素注射都未見發情的牛隻，繼續進行發情觀察，若穩定發情則給予人工授精。所有牛隻於人工授精後 60 日直腸觸診驗孕，記錄所有資料進行分析。

5.3.3 長期飼養於水簾牛舍的泌乳牛的繁殖效率

收集 2008 至 2010 三年間泌乳牛分娩資料 (初產牛隻不參與紀錄)，由分娩日回推配種日，並確認該母牛該胎次所有配種次數與配種時所在牛舍。試驗設計採

用卡方 (χ^2) 設計，以牛隻懷孕的配種日為分析觀測值，並區分為涼季受孕 (11 月到翌年 4 月) 或熱季受孕 (5 月至 10 月)，及飼養於水簾+噴水牛舍或一般牛舍。同期間，也收集飼養於一般牛舍的乾乳牛的配種紀錄，做為對照比較。

由於2006 年水簾+噴水牛舍評估結果，顯示可以促進牛隻採食量及乳量 (Shiao *et al*., 2011)，因此其後牛群現場管理即將高產泌乳牛飼養於水簾+噴水牛舍，一般牛舍則飼養中低產泌乳牛，兩群牛隻依其平均乳量提供高產或低產完全混合日糧，其餘飼養管理皆相同。一般牛舍與水簾+噴水牛舍的噴水降溫措施相同，如前 5.3.2.2 一節所述。

5.4 結果與討論

5.4.1 水簾牛舍對熱季泌乳牛血中助孕素濃度之影響

2005 年試驗，水簾牛舍白天最高換氣速度僅每分鐘 2 次。水簾牛舍飼養環境對夏季荷蘭泌乳牛血清助孕素濃度之影響，詳如圖 5.1 所示。不論是在配種前 3 日、配種時或配種後 7 日，水簾牛舍與一般牛舍環境對牛隻血清中助孕素濃度皆無顯著性 ($P > 0.05$)。2005 年水簾牛舍飼養環境明顯減低牛隻的採食活動，只有一般牛舍牛群 57%的採食活動 (採食比例分別為 35.7% 與 62.1%，$P < 0.05$)，牛隻乾物質採食量隨之降低 7.6% (17.0 kg *vs*. 18.4 kg)，牛隻 4%乳脂校正乳量隨之降低 10.1% (23.1 kg *vs*. 25.7 kg, $P < 0.001$)，但這個乾物質採食量的降低，並未如 Khodaei-Motlagh *et al*. (2011) 所述，乾物質採食量的降低會造成血中助孕素濃度的降低，然而本次試驗牛隻頭數不足與個體變異大，也都可能是差異無法顯現的原因。

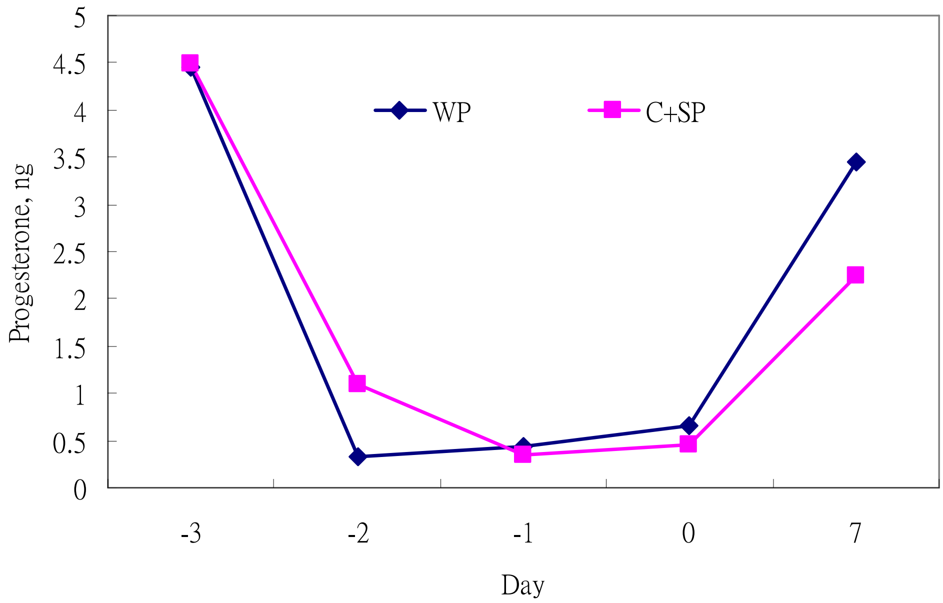

圖 5.1　水簾牛舍飼養環境對熱季荷蘭泌乳牛血清助孕素濃度之影響。

Figure 5.1　Effect of water-padded (WP) barn environment on the serum progesterone concentration of lactation Holstein cows in hot summer. C+SP indicates the control free stall barn with sprinkler cooling.

5.4.2 水簾牛舍對熱季泌乳牛標的配種計畫效果之影響

2007 年夏季試驗結果顯示，於熱季期間試驗牛隻不論在一般牛舍對照組或水簾+噴水處理組，對於前列腺素注射發情同期化處理的反應皆不理想。第一劑前列腺素注射對照組 19 頭 (1 頭於前列腺素注射時發情配種) 與處理組 19 頭 (1 頭於前列腺素注射前淘汰)，發情配種頭數分別為 8 頭 (42.1%) 與 6 頭 (31.6%)；第二劑前列腺素注射對照組 7 頭與處理組 10 頭，發情配種頭數分別為 4 頭 (57.1%) 與 5 頭 (50%)；全期試驗對照組與處理組發情配種頭數分別為 29 頭次與 23 頭次，於人工授精後 60 日直腸觸診驗孕，對照組與處理組懷孕頭數僅分別為 6 頭與 4 頭；對照組與處理組每次人工授精受孕率分別為 20.7%與 17.4% (表 5.1)；若以三個月全期的懷孕率來看，對照組與處理組分別為 30% (6/19) 與 21.1% (4/19)。雖然在 2006 年試驗結果顯示水簾+噴水組牛隻乳量有高於傳統組的趨勢 (25.4 kg *vs.* 24.7 kg, $P = 0.10$) ，但由表 5.1 整體繁殖效率的表現數據評估，熱季泌乳牛隻飼養於水簾+噴水牛舍，並未能有效改善熱季繁殖性能，水簾+噴水組的繁殖效率甚至有較一般牛舍組為低的趨勢。

表 5.1　水簾牛舍環境對熱季泌乳牛標的配種計畫效果之影響

Table 5.1　Effect of water-padded barn environment on the efficiency of target breeding of lactation Holstein cows in hot summer

Treatment	Convention barn		Water-padded barn	
	n	AI (%)	n	AI (%)
1st PG injection	19	8 (42.1)	19	6 (31.6)
2nd PG injection	7	4 (57.1)	10	5 (50.0)
Non PG injection		17		12
Total Pregnancy		Pregnancy (%)		Pregnancy (%)
	29	6 (20.7)	23	4 (17.4)

5.4.3 長期飼養於水簾牛舍的泌乳牛的繁殖效率

收集2008至2010三年間泌乳牛的分娩資料，回推的配種資料含括2007至2010年3月止。所收集資料共有138頭牛隻分娩與329頭次配種數據，涼季 (11月到翌年4月) 有82頭分娩與157頭次配種資料；熱季 (5月至10月) 有56頭分娩與172頭次配種資料，圖5.2依此些資料計算牛隻在水簾+噴水牛舍與一般牛舍的配種效率。一般牛舍乾乳牛的懷孕率在熱季、涼季與全年分別為 65.2%、69.2%與67.3%，顯示乾乳牛全年可以維持高的懷孕率且不受季節的影響。泌乳牛熱季飼養於水簾+噴水牛舍或一般牛舍的配種效率相近，分別為26.4%與29.0%，僅達同期乾乳牛的40.5% 與44.5%；泌乳牛涼季飼養於水簾+噴水牛舍與一般牛舍乾乳牛的配種效率，分別為 44.3% 與 68.0%，飼養於一般牛舍泌乳牛與同期乾乳牛的配種效率相近，而飼養於水簾+噴水牛舍泌乳牛的配種效率，涼季雖然較熱季為高，但仍僅達到同期另二牛群的65%。

2006年水簾+噴水牛舍評估，顯示可以促進牛隻採食量及乳量，因此根據此結果將高產泌乳牛飼養於水簾+噴水牛舍，中低產泌乳牛則飼養於一般牛舍，兩群牛隻各採食其高產或低產完全混合日糧。涼季飼養於水簾+噴水牛舍泌乳牛的懷孕率低於一般牛舍的中低產泌乳牛與乾乳牛，高泌乳性能應是其原因之一。Purwanto *et al.* (1990) 研究指出，高產 (31.6 kg/d) 與中產 (18.5 kg/d) 泌乳牛，其熱生成分別較乾乳牛熱生成高出 48.5% 與 27.3%，因此高產泌乳牛高的採食與代謝速率大幅提高了牛隻的熱生成，若無法妥善的紓解，將嚴重影響牛隻的生殖系統的熱環境

與能量供應，使懷孕率明顯降低。Igono and Johnson (1990) 指出高產泌乳牛對熱緊迫影響繁殖性能表現上確實較中產泌乳牛敏感。另一個可能原因推測為舍內風速不足而影響牛隻熱的排除，當期水簾+噴水牛舍電腦設定啟動補充抽風扇的氣溫為 24℃，因此估計涼季時牛舍內應僅有基礎風扇數的運轉，牛隻周遭的風速與空氣交換速度分別為 1.17 m/s 與 1.4 次/min，這個風速遠較 Shearer *et al*. (1991) 建議的 2.5 - 3 m/s 為低，因此涼季亦造成水簾+噴水牛舍內牛隻無法藉蒸散作用來紓解熱緊迫。

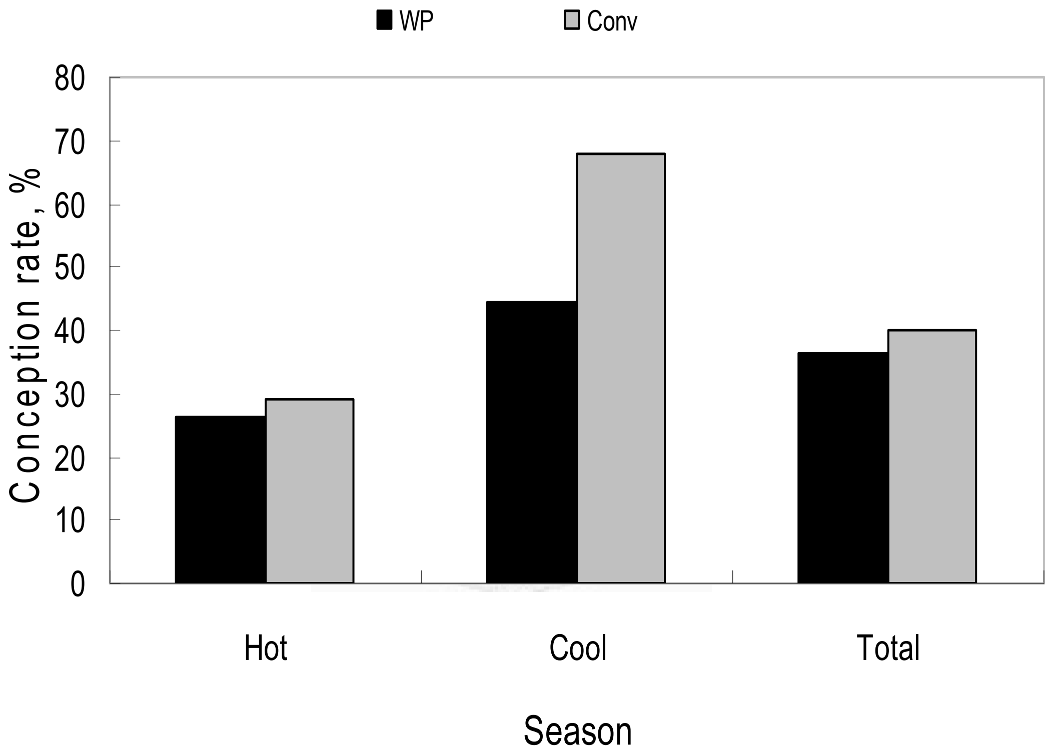

圖 5.2　自 2008 至 2010 三年間涼熱季泌乳牛飼養於水簾牛舍 (WP) 或一般牛舍 (Conv) 的懷孕率表現。

Figure 5.2　Performance in conception rate of lactation Holstein cows raised in a water-padded (WP) barn or a conventional free stall barn during cool or hot season from 2008 to 2010.

為處理這個問題，研究團隊採取將水簾牛舍補充風扇啟動溫度調低至 20℃、以涼水 (20-25℃) 間歇噴霧方式取代水簾、再配合低長纖高副產物的飼糧配方與良好的季節配種等措施，今年 (2011) 夏季隧道式間歇噴霧+噴水牛舍全日風速明顯增加並且涼爽，泌乳牛群性能表現良好，七月份 DHI 測乳資料顯示，全場 78 頭荷蘭種泌乳牛的泌乳天數雖然已 214 天，但每頭牛平均日產乳量仍保持在 28.4 kg，

乳脂 3.93%與乳蛋白質 3.13%，而 305-2X-ME 達 9,182 kg。與 2010 年同期相比較乳量明顯的增高，同時進入熱季亦未見大幅降低泌乳量的現象 (圖 5.3)。

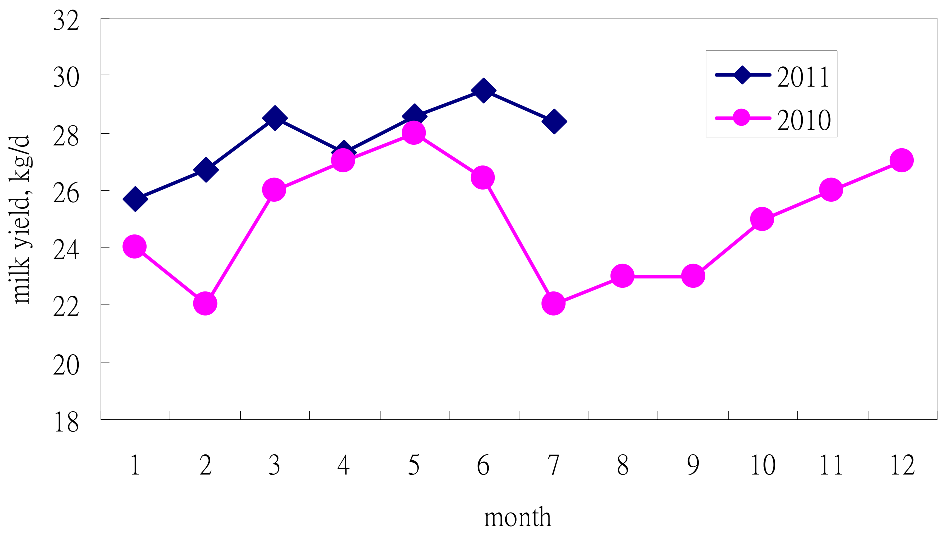

圖 5.3　增加牛舍風速、噴霧+噴水降溫與高纖高副產物飼糧對荷蘭種泌乳牛 2011 年夏季乳量的改善效果。

Figure 5.3　Effect of combining of higher air speed, mist+sprinkling cooling, and high fibrous by-product diet on the improvement of milk yields of Holstein cows in 2011 summer.

5.5 結論

經由血中助孕素濃度調查、標的配種的實施與三年連續追蹤泌乳牛繁殖性能的田間試驗等一系列研究，2007 年至 2010 年所使用的水簾+噴水降溫模式，並無法達到提高泌乳牛繁殖性能之目的。持續牛舍內高濕度與低風速應是其主因，因為無法有效紓解體內熱的積聚，在 2011 夏季的牛舍環境參數調整與蒸發冷卻方式的改善下，牛群泌乳性能已有良好的提升，本研究團隊將再次探討改善後的牛舍環境是否有益於牛群繁殖性能的表現。

第六章 結　論

綜合三階段的試驗結果，水簾牛舍在風速 1.66 m/s 與 2 次/min 的換氣速率下，飼養泌乳牛非但沒有紓解熱緊迫效果，反而會增加牛舍內相對濕度，造成牛隻無法借蒸散作用紓解體內之熱積聚，導致採食量與乳量顯著的低落。增加水簾牛舍的排風扇，使達到風速 2.38 m/s 與 3.2 次/min 的換氣速率，再輔以噴水降溫，雖無法完全紓解泌乳牛熱緊迫，但在採食與泌乳都已相當於或優於傳統組牛隻表現。經由血中助孕素濃度調查、標的配種的實施與三年連續追蹤泌乳牛繁殖性能的田間試驗等一系列研究，無法達到提高泌乳牛繁殖性能之目的。

持續牛舍內高相對濕度與低風速應是其主因，造成牛隻無法有效紓解體內熱的積聚，如何增加牛舍內通氣量與降低相對濕度，為往後努力的方向。在 2011 夏季的牛舍環境控制參數的調整與蒸發冷卻方式的改善下，牛群泌乳性能已有良好的提升，本研究團隊將再次探討改善後的牛舍環境是否有益於牛群繁殖性能的表現。

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Interpretive Summary

Feasibility Assessment of a Tunnel-ventilated, Water-padded Barn on Alleviation of Heat Stress for Lactating Holstein Cows in a Humid Area. *By Shaio, et al., page* .

In Taiwan, persistently hot and humid weather seriously restricts cow welfare and milk production. Heat stress is most directly and effectively improved by improving the barn environment. In this study, we evaluated the contributions of a tunnel-ventilated and water-padded barn to reducing cow heat stress. It is found that increasing air speed and using sprinkler cooling benefited the cows and improved their lactation performance. This modified barn environment is more comfortable for lactating Holstein cows.

A TUNNEL-VENTILATED, WATER-PADDED BARN IN A HUMID AREA

Feasibility Assessment of a Tunnel-ventilated, Water-padded Barn on Alleviation of Heat Stress for Lactating Holstein Cows in a Humid Area[1]

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ABSTRACT

The use of evaporative cooling for mitigating heat stress in lactating cows in humid areas is controversial. In Taiwan, Holstein cow performance is significantly restricted by hot and humid weather. This study investigated the efficacy of using a tunnel-ventilated, water-padded freestall (**TP**) barn for reducing heat stress in lactating cows. From August to October 2006, 36 cows allocated in a 3 x 3 Latin square were raised in 3 barn cooling treatments: a conventional freestall barn with fans and sprinklers in the feed line (Fan+SP, control), a TP barn and a TP barn with sprinkler cooling (TP+SP). Daytime air speeds in the three barns were 1.23, 2.38 and 2.06 m/s, respectively. Both TP barns were more efficient in reducing the daytime temperature and the temperature-humidity index. The barn temperature was <26°C for an extra 4.2 h per day, but the relative humidity was >96% in both TP barns. Cows in both TP barns had higher respiration rates and skin temperatures at 0300 h than cows in the Fan+SP barn. The TP environment increased the cows' serum cholesterol level and the activity of alkaline phosphatase and alanine aminotransferase, but blood partial pressure of CO_2 was not affected. Vaginal temperature was persistently high in cows in the TP barn; in the 2 SP barns, it decreased 0.4 to 0.6°C following sprinkling and milking. The intake activity and rumen digestion of cows raised in the 3 environments were similar. Cows in both TP barns ingested more dry matter. Cows in the TP+SP barn tended to produce more milk than those in the Fan+SP barn (25.4 vs. 24.7 kg). Although heat stress was not completely alleviated in these 3 barns, the TP+SP treatment resolved the negative effect of a previous TP barn built in 2004 on intake and milk yield by increasing air speed and using sprinkler cooling. Thus, it is expected that TP+SP barns will be beneficial in regions with high humidity. Adequate air speed and sprinkler cooling are likely to be key factors for further study.

Key words: heat stress, lactating Holstein cows, humidity, a tunnel-ventilated, water-padded barn

INTRODUCTION

Because of their large body size and high metabolic rates, lactating cows, especially high-producing cows, are extremely sensitive to heat stress. Environmental contributors to heat stress include air temperature (**T**), relative humidity (**RH**), solar radiation, air speed, and their interactions. When the effective T is higher than the animal's thermo-neutral zone or comfort zone, heat stress occurs (Bianca, 1962). To dissipate the extra heat, cows look for shade and increase their drinking, sweating, urination and panting rates (Bucklin et al., 1991; Smith et al., 2006a). If heat dissipation is inadequate, serious heat stress will result in higher body T and lower DMI, milk yield and reproduction performance (West, 2003).

Taiwan is an isolated island located in subtropical Asia. For the last decade, the average monthly T and RH during the hot summer months have reached 27.1ºC and 84%, respectively (Table 1). In addition, persistently high humidity even worsens the environment for cows in Taiwan. Heat stress, which is significantly detrimental to cow performance, is the main challenge to our dairy industry. Beede and Collier (1986) suggested that improving the barn environment is the most effective and direct method to alleviate cow heat stress. Barns that provide shade to cows are necessary in Taiwan. Feed line fans and sprinklers cooling, which were introduced from Israel, decrease cow rectal T and respiration rate (**RR**) and effectively stimulate feed intake (Lee et al., 1999). However, the barn temperature-humidity index (**THI**) of the cool, warm and hot seasons remains high even in well-managed dairy farms (66.3, 75.7 and 79.8, respectively). Thus, the cows still suffer heat stress (THI >72) for two-thirds of the year (Chen et al., 2009).

Tunnel ventilation used in a pad-cooled barn contributes to heat stress relief. Evaporating water in the pad absorbs heat from the incoming air. The resulting cooled air removes body heat when it flows over cow body surfaces. In dry areas, using water to evaporate heat has been shown to effectively reduce cow heat stress (Bengtsson and Whitaker, 1988; Ryan et al., 1992). However, the presence of high humidity causes concerns regarding the use of water to relieve heat stress in humid areas. In the hot, humid climate of Mississippi, Smith et al. (2006a,b) showed that combining tunnel ventilation with evaporative cooling decreased cow exposure to mid-heat stress, increased feed intake and milk yield, and decreased milk SCC relative to that in a freestall barn with fans and sprinklers. Their 2-yr study suggested that a tunnel-ventilated barn with evaporative cooling could work well, even in humid areas.

Open-shed barns attract pigeons and sparrows. To improve barn cooling and prevent epidemic disease, a tunnel-ventilated, water-padded freestall (**TP**) barn was built at the Livestock Research Institute (**LRI**) in Taiwan in 2004 and was evaluated in 2005. The maximum daytime air speed in the barn was 1.66 m/s (air exchange rate of 2 times/min), and RH was ≥93.5% throughout the day. Cow RR and rectal T increased, and DMI and milk yield significantly decreased. Thus, the TP barn decreased daytime barn T and THI but increased the heat load of the cows (Shiao et al., 2009a,b). Low air speed and high RH were postulated to be the reasons for these responses. Because direct wetting and fan drying is the most effective and economical method for cooling cows (Hillman et al., 2005), the TP barn was remodeled by doubling the number of exhaust fans, applying sprinkler cooling and increasing the outside shade. The feasibility of relieving heat stress was re-evaluated with these new parameters and is reported in this paper.

MATERIALS AND METHODS

Barn Treatment

The trial was conducted in the LRI experimental farm from August to October 2006. Three barn cooling treatments were established in 2 adjacent barns, 1 in the conventional freestall barn and 2 in separate pens within 1 water-padded barn. A conventional freestall barn with fans and sprinkler cooling in the feed line (**Fan+SP**), commonly used in Taiwan, was used as the control. The Fan+SP barn has the following dimensions: a maximum roof height of 11.8 m, side eaves of 3.4 m and a total area of 60 m × 30 m. Four fans (1.5 kW, 0.9 m diameter, 3 blades, capacity 26,300 m^3/h) hung above the stalls and the feed line in the 12 m × 10 m experimental pen, were operated 24 h/d. Based on the results of our previous sprinkler cooling (Lee et al., 1999) and night feeding studies (Lee et al., 2003), a line of sprinklers positioned above the headlock was turned on 8 times a day (0800, 0900, 1000, 1550, 1650, 1750, 2200 and 2300 h) for 30-min rounds. Each round of sprinkling included six 5-min cycles with 1 min of water spraying. The quantity of water sprayed was 2.4 L/min per sprinkler. A detailed floor plan of the TP barn was described in an earlier report (Shiao et al., 2009a). The water-padded barn was constructed with an inside volume of 50 m long × 15 m wide × 2.5 m high. An L-shaped water pad (20.2 m long × 0.45 m wide × 1.8 m high) built from 3 layers of cubic honeycomb plastic was set at one side of the barn. At the other side of the wall, 16 exhaust fans were stationed that were identical to those used in the Fan+SP barn. A plastic curtain was hung at the 2 long sides to produce the tunnel effect. The airflow of the TP barn was controlled linearly by the Fancom F-Central system (Fancom Agri-Computers, Panningen, Netherlands). When barn T decreased below 26ºC, 6 fans operated to provide the minimum fresh air. Two fans per group were turned on for every 0.8ºC increase in T until a maximum of 14 fans were operating. A water pump circulating water on the water-pad was also turned on when barn T >26ºC. The cow allocation area (42 m long × 11 m wide) was horizontally divided into four equal pens in the water-padded barn. The pen closest to the water pad was designated as the TP treatment, and the third pen nearer the fan wall and with same sprinkling program as that of Fan+SP barn was designated as the **TP+SP** treatment. The facilities, including stall, water trough, headlock and floor plan, of these three experimental pens were similar. Twelve cows were housed in each pen, with the between 9.6 and 10 m^2 of space per cow.

Cow Management

All animal use protocols were reviewed and approved by the Institutional Animal Care and Use Committee of the LRI. A 3 × 3 Latin square design with a 21-d period was applied. Thirty-six lactating Holstein cows were assigned into 3 groups based on their milk yield, parity, DIM and BW. The average conditions before the trial were 24.5 ± 4.2 kg of milk yield, parity 1.5 ± 0.9, 143 ± 69 DIM, and 540 ± 67 kg of BW. Each group contained 1 rumen-cannulated lactating cow. Cows were milked twice daily at 0500 and 1530 h and fed fresh TMR ad libitum at 0700 h (one-third of total) and 1500 h (two-thirds of total). This diet, which provided the nutritional requirements for 28 kg of milk yield (NRC, 2001), was composed of 11.1% corn silage, 20.6% napiergrass silage, 18.2% alfalfa hay, 15.3% silage of wet brewers grains and corn, 9.0% soybean hull pellet, and 25.8% corn-soybean meal grain mixture (DM basis). The diet contained 38.2% DM, 16.2% CP, 42.6% NDF and 1.54 Mcal of NE_L/kg (DM basis). At the beginning and end of each period, BW was measured on 2 consecutive days at 0810 h, before feeding.

Barn Environment

During the 63-d trial period, barn T and RH were measured every 0.5 h by using a total of 12 HOBO Pro RH/Temp meters (Onset Computer Corp., Bourne, MA). Four thermometers were hung at the front and back of each experimental pen above the headlock and stall positions, 2 m above the ground. The measured data were transferred weekly onto a computer. The 4 T and RH readings from each pen were averaged first by time and then across days to plot the diurnal changes and to calculate the THI (THI = 9/5 × T + 32 - 0.55 × (1 - RH) × (9/5 × T - 26)), with T in ºC and RH in decimal (NOAA, 1976). In this paper, THI is categorized in 4 levels, with THI ≤72, 72 < THI ≤78, 78 < THI ≤84, and THI >84, representing cows that are comfortable, mildly stressed, moderately stressed, or seriously stressed, respectively (Armstrong, 1994; Hahn et al., 2009). On each Monday and Friday, air speed was measured using a hot wire anemometer at the front and back of each pen, at a height of 1.5 m (cow-level), at 3 measuring locations (the TMR trough, feed line, and walk alley between stall rows) and 3 time points (0830, 1330, and 1630 h). Air speed data for each treatment and location were averaged first by time and then across days.

Physiological Responses

Individual cows' RR were counted for 2 periods of 30 s at 0300 and 1300 h for 2 d each period. The skin T of the central part of the neck and backside was measured simultaneously using an infrared thermometer (10-s reading period at a distance of 1 m). To estimate the body core T, individual vaginal T was measured every minute for 24 h by using a HOBO Water Temp Pro Data Logger (Onset Computer Corp.) inserted into a blank control internal drug release (CIDR, Eazi-Breed, Pfizer Animal Health, New York, NY) device. Before application, the progesterone in the device was thoroughly washed out with alcohol.

On 2 d during each 21-d period, 2 blood samples were collected from the jugular vein of each cow at 1300 h. The first sample was placed in a Monovette tube without heparin. After standing for 30 min, the blood was centrifuged at 1,200 × g for 15 min to obtain serum that was then frozen for future analyses, including tests for albumin (**Alb**), total protein, Ca, P, glucose, cholesterol (**Chol**), BUN, aspartate aminotransferase (**AST**), alanine aminotransferase (**ALT**), alkaline phosphatase (**ALP**), and lactate dehydrogenase (**LDH**). An autoanalyzer was subsequently used for these measurements

(Data Pro Plus Random Access Clinical Analyzer, ThermoTrace, Victoria, Australia). The second blood sample was placed in a Blood Gas Monovette tube, left on ice and analyzed for blood pH, partial pressure of O_2 (**pO_2**), and partial pressure of CO_2 (**pCO_2**) using a pH/Blood Gas Analyzer (model 16200-06, Instrumentation Laboratory, Milan, Italy).

Intake, Rumen Digestion and Lactation Performance

The amount of TMR offered, next-day refusals, and the actual number of cows in each group were recorded daily. Individual feed ingredients were sampled twice each period. Fresh TMR and next-day refusals were sampled daily during the last 10 d of each period for DMI measurement. All samples were stored at -20ºC before undergoing 48 h of drying at 55ºC followed by pooling, grinding, and analyses. During the last 10 d of each period, cow activity was monitored by video. Two days were selected to count eating and resting activity (e.g., number of cows eating/total cow number × 100%) every 10 min. Continuous 48-h rumen digestion was traced by rumen content sampling at 0700 (0 h, before a.m. feeding), 0900, 1100, 1300, 1500 (8 h, before p.m. feeding and milking), 1800, 2000, 2200, 0000, 0230, and 0500 h (22 h, before a.m. milking), respectively. Rumen content was filtered, and pH was measured immediately, and then contents were acidified with 50% sulfuric acid (50:1, vol/vol), and stored at -20ºC. After centrifugation, the supernatant was analyzed for VFA concentration using gas chromatography with a flame ionization detector (CP-3800, Varian Inc., Walnut Greek, CA) and for NH_3-N concentration using a spectrophotometer. Individual milk yields were recorded on a daily basis, and 2 a.m.-p.m. milk samples from each cow were sampled for milk composition analyses during each period (CombiFOSS 5000, FOSS Analytical A/X, Slangerupgade, Denmark) in the Hsin-chu Branch of LRI.

Statistical Analyses

Relative environmental measures were expressed as the means ± SD. Bovine data, including RR, vaginal T, blood gases, serum biochemical metabolites, rumen pH, VFA and NH_3-N, BW, milk yield, and milk composition were analyzed using individual cows as the observation unit. Dry matter intake and intake activity were analyzed on a group basis. Data were analyzed using a general linear model in SAS (SAS Institute, 2003) with the Latin square model. Least squares means and variations were used to compare the cooling effect among 3 barn treatments at a significance level of $P < 0.05$. If the P-value was close to 0.10, the presence of a tendency was noted.

RESULTS AND DISCUSSION

Barn Environment

The pattern of diurnal changes of barn T, RH, and THI did not change between 2005 and 2006 (Shiao et al., 2009a). As expected, both the TP and TP+SP barns more effectively reduced daytime barn T (Figure 1A). The 2 TP barns prevented barn T from exceeding 30ºC, but cows in the Fan+SP barn experienced 4.5 h per day of T >30ºC. The maximal barn T in the TP and TP+SP barns were 3.7ºC and 3.1ºC lower than that in the Fan+SP barn, respectively (27.8 and 28.4 vs. 31.5ºC). The magnitude of reduction was consistent with the results of Smith et al. (2006a), who reported a decrease of 3.1ºC, and was greater than the 2.4ºC decrease we noted in our 2005 study (Shiao et al., 2009a). Berman et al. (1985) suggested that the highest critical T for dairy cows was approximately 25ºC to 26ºC. The length of the cool period (barn T <26ºC) in both TP barns increased by 35% (4.2 h per day) relative to that in the Fan+SP barn (16.2 vs. 12.0 h) .

The daytime RH inside the Fan+SP barn was inversely correlated with barn T: the lowest RH of 68.7% was observed at the hottest time of day (noon). The RH in the Fan+SP barn was also close to 100% for 69% of each day (16.5 h), with higher levels of humidity predominating at night. A persistently high RH, >96% during the entire day, was found in both the TP and TP+SP barns (Figure 1B). Consistent with this finding, other studies conducted in humid areas have shown high RH in water-padded barns (Smith et al., 2006a; Brouk et al., 2010). These findings have stimulated discussion regarding the appropriateness of water padding in humid regions. Many studies have supported the observation that humidity affects heat stress more strongly than does temperature. Humidity affects the critical T at which cows feel comfortable. At low RH, the critical T can be as high as 27°C; at higher RH, the critical T decreases to 22°C, and cows begin to suffer heat stress at this relatively low temperature (Armstrong, 1994; West, 2003). High humidity inhibits sweating. Maia et al. (2005b) reported that the sweating rate decreased from 500 to 60 g H_2O/m^2h when RH increased from 30 to 90%.

Importantly, the severity of high humidity can be partially mitigated by high air speed. When the air speed crossing a cow's body surface increases from 0.2 to 0.9 m/s, the animal's sweating rate increases from 75 to 350 g H_2O/m^2h (Hillman et al., 2001). However, if the air speed used for mist cooling is not high enough, small water droplets accumulate on the cows' surface hair and form an insulating barrier that prevents heat dissipation (Hahn, 1985). Thus, air speed plays an influential role in determining the utility of water-padded barns.

In this study, 14 fans in the water-padded barn were operated during most daytime hours. The average daytime cow-level air speed reached 2.38 m/s in the TP barn (Table 2). In the TP+SP barn, which was located in the third pen from the air inlet, the air speed decreased to 2.06 m/s. The highest calculated daytime air exchange rate in the barn was 3.2 times/min. The greater number of fans in the newer (2006) water-padded barns increased air speed and air exchange rates relative to the TP barn constructed in 2005 (1.66 m/s and 2.0 times/min, respectively). Without the tunnel effect, the air speed in the Fan+SP barn reached only 1.23 m/s (52% and 60% of that in the TP and TP+SP barns, respectively). At night, barn T in the 2 water-padded barns was <26ºC (Figure 1A). At this temperature, the computer only activated 6 fans. The air speed and air exchange rate were estimated to be only 1.17 m/s and 1.4 times/min, respectively. The effectiveness of cooling the cow by direct wetting depends on air speed. Bray et al. (1992) and Gooch and Timmons (2000) recommended using an air velocity of at least 2 to 3 m/s over the cows' backs with a fan and sprinkler system for a freestall barn. Chastain and Turner (1994) suggested that the air speed required to dry the soaked cows in a humid area was 2.9 to 4.0 m/s. In this study, the daytime air speed of 2.38 to 2.06 m/s in water-padded barns was within or below the recommended range. However, the nighttime air speed of 1.17 m/s was far below the recommended air speed, and this factor might seriously restrict cow heat dissipation. We believe that the significantly increased panting rate and skin T of cows in water-padded barns during the cool night was a direct cow response of this low air speed.

Temperature-humidity index is commonly used as an indicator of cow heat stress, but its appropriateness has been questioned. It was originally designed for dry environments (Armstrong, 1994). Sprinklers and fans relieved heat stress effectively but did not decrease environmental THI. However, after comparing the T, RH, wind speed, and THI with Holstein cow rectal temperatures in a subtropical environment, Dikmen and Hansen (2009) suggested that THI would be a good predictor for heat stress. In this study, THI values supported the argument that none of the 3 barn cooling methods could offer a comfortable environment for dairy cows. Cows always lived under mild ($72 < THI \leq 78$, nighttime) to moderate ($78 < THI \leq 84$, daytime) heat stress (Figure 1C).

Physiological Responses

Respiration Rate and Body Temperature. Four cows were removed from the trial because of mastitis or drying. The cows' RR was positively correlated with air T (Hahn et al., 1997). Cow RR begins to increase when the ambient T reaches 19°C, and sweating commences at 25°C (Hahn et al., 1997; Maia et al., 2005a,b). Under heat stress conditions, the cows' skin T was closely related to their RR (Collier et al., 2006). At 1300 h, all cows panted at an average of 54 times per min (Figure 2A). Cows in the TP and TP+SP barns had higher RR at 0300 h compared with those in the Fan+SP barn (53 vs. 42 times/min; $P < 0.001$). Respiration rate responses varied across cooling conditions. Cows in the Fan+SP barn panted harder when barn T increased, but cows in the 2 water-padded barns panted hard even in the cool early morning. Skin T measured at 0300 h was correlated with RR, with cows in TP and TP+SP barns having higher skin T than those in the Fan+SP barn (Figure 2B and 2C). The back skin T of cows in these 3 barns was 28.92, 29.27, and 28.31°C, respectively ($P < 0.001$) in TP, TP+SP, and Fan+SP. Skin T increased with increasing barn T. At 1300 h, the back skin T readings were highest in the Fan+SP barn, intermediate in the TP+SP barn, and lowest in the TP barn with values of 32.48, 31.60 and 31.04°C, respectively ($P < 0.001$). This daytime skin T trend correlated well with the barn T and cow heat load.

Regardless of when they were measured (cool early morning or during the hot noontime), cow RR measured in this trial were markedly higher than the 26 to 35 breaths/min recommended for comfortable cows (Reece, 1993). The high RR response corroborated the barn environment measurement results and confirmed that the 3 cooling treatments still left cows in a condition of heat stress. Around 0300 h, the 3 barn environments were similar (Figure 1), but the RR and skin T from cows in TP and TP+SP barns were significantly higher. This phenomenon suggested that factors other than T and RH influenced the cows' heat load. Air speed is definitely a contributing factor. The nighttime air speed in water-padded barns was only 50% (1.17 m/s) of that in the daytime, and it was much lower than the recommended 2 to 3 m/s (Bray et al., 1992; Gooch and Timmons, 2000). The effectiveness of intrinsic sweating or external sprinkling was reduced due to this significantly lower air speed (Hillman et al., 2001). Cows were therefore forced to pant hard to dissipate body heat during the cool night. Thus, the 26°C T setting that controls the minimum number of operating fans should be lowered to increase the nighttime air speed. The type of barn might also affect the heat stress mitigation. When the air T cools, cows and the surrounding barn structure surface can dissipate accumulated heat by radiation into the cool night air (Hahn, 1994). In a closed, tunnel-ventilated barn, this radiant heat exchange is likely to be restricted.

Unlike the more dynamic (and indicative of current environment) RR and skin T, vaginal T representing body core T was measured. The highest vaginal T of cows raised in the 3 environments was similar (39.59°C; Table 3). The diurnal variation in vaginal T change was very interesting (Figure 3). The vaginal T of cows in the TP group was persistently high (38.9 to 39.2°C). The maximal reduction of 0.15°C occurred after 2 milkings. The cows in the TP+SP condition, although housed in the same building, reacted differently. Their diurnal variation resembled that of cows in the Fan+SP barn. Cow vaginal T measurements from 2 SP treatments were reduced by 0.4 to 0.6°C after 2 milkings and, more importantly, after initiation of sprinkler cooling. This phenomenon explicitly illustrates the effectiveness of wet and fan cooling. Hillman et al. (2005) further reported that, when standing cows received 17 min of spraying and fan, vaginal T decreased at a rate of -0.5°C/h. If the spray and fan treatment was extended to 64 min, the reduction rate of vaginal T increased to -1.02°C/h. Berman (2010) also found that, during 7 spray and fan cycles, the skin T of wet skin decreased more quickly than that of dry skin. Israeli researchers have emphasized multi-cooling methods using spraying and fans in the holding area for high-yielding cows (Flamenbaum and Ezra, 2007). Results from this study have shown that spray and fan methods can efficiently increase heat evaporation even in an extremely humid environment (RH near 100% in the water-padded barn). This finding was consistent with research conducted in Kansas, Florida, and Thailand, which demonstrated that a combination of tunnel ventilation, evaporative cooling and spraying significantly reduced cows' RR and body T (Brouk et al., 2010).

Blood Gas. Heat stress affects the physiological acid-base balance (West et al., 1992). When heat load increases, cows increase heat evaporation from the upper respiratory tract by panting more frequently. However, panting lowers blood CO_2 and results in respiratory alkalosis, revealed in blood gas analysis by decreased pCO_2, decreased HCO_3^- level and increased pH (Sanchez et al., 1994; Calamari et al., 2007). In our 2005 study of cows in the TP barn, low air speed and high humidity caused a serious heat burden, resulting in respiratory alkalosis (Shiao et al., 2009a). In contrast, all cows in this study had similar blood pCO_2, although the blood pH of cows in the TP barn tended to be lower ($P = 0.08$) (Table 4). This implied that the increased air speed and sprinkler cooling in the water-padded barn applied in this study helped heat dissipation. Blood pO_2 was higher in cows in the Fan+SP barn, an effect that might be related to the barn type. Sabuncuoglu et al. (2008) reported that, during the cold season, the higher airflow of an open-shed barn contributed to a higher blood pO_2 relative to a closed-type barn.

Serum Metabolite. Serum metabolites have been studied to identify markers of bovine heat stress. The pattern of serum metabolites was consistent between our 2005 and 2006 studies. The serum Alb, BUN, Ca, glucose, AST, and LDH of cows in the Fan+SP and TP barns were similar. Cows in the TP barn had higher serum total protein and P and lower Chol, ALP and ALT. The serum metabolites of cows in the TP+SP barn resembled the trend of cows in the TP barn, with the exception of low serum P levels (Table 4).

Serum protein and BUN reportedly increase when air T increases from 18 to 32°C (Koubková et al., 2002). In this study, the serum total protein of cows in both water-padded barns increased, but Alb and BUN were similar to those of cows in the Fan+SP barn. Other studies found that the hot season caused lower plasma glucose, Chol and ALP in Holstein cows (Abeni et al., 2007; Calamari et al., 2007). In our study, serum Chol and ALP were relatively decreased in both water-padded barns, but glucose level was not. Both AST and ALT are involved in the transfer of amino groups. The ALT activity of high-producing cows decreases with increasing air T (Koubková et al., 2002). In our study, ALT was lower in cows housed in water-padded barns, but AST activity tended to be higher ($P = 0.10$). The serum P level of cows in the TP barn was higher than that in the 2 SP groups, which is consistent with previous results (Shiao et al., 2009a). In the Sanchez et al. (1994) study, phosphorus absorption decreased by 50% in heat-stressed cows. It was thus postulated that lower absorption led to accumulation of P in the serum and decreased the P available for cellular ALP synthesis. The high serum P and low serum ALP in cows in the TP barn support this hypothesis. However, the low serum P and intermediate ALP activity of cows in the TP+SP barn seem to indicate lower heat stress relative to the TP barn. Further research is required to verify this hypothesis. Overall, these serum analyses did not clearly indicate the heat stress level associated with the 3 cooling treatments investigated in this study.

Intake, Rumen Digestion and Lactation Performance

Intake Activity. Quantification of recorded behaviors revealed that cows in the 3 barn treatments spent similar amounts of time per day eating (4.8 to 5.7 h) and lying down (11.5 to 12.3 h; Table 5). Cow comfort studies recommend that lactating cows should eat for 3 to 5 h and rest for 12 to 14 h/d (Grant, 2007). Relative to the ideal condition, cows spent more time eating and less time lying down in the hot and humid conditions of this trial. This observation is consistent with cow behavior studies that demonstrate that cows suffering heat stress eat more frequent, smaller meals and, to increase the surface area available for dissipating body heat, stand for a longer periods of time.

After 2 offerings of fresh TMR, cow intake increased significantly (Figure 4). Forty-three to 54% of cows ate up to 2 h after the a.m. feeding. During an extended period after the p.m. feeding, 51 to 68% of cows were eating 2.5 h after feed offering, and cows in the Fan+SP barn were more willing to eat than cows in the TP barn ($P = 0.11$, Table 5). Intake activity in other periods was generally lower than 25%. The lowest intake activity (only 6.3 to 12.6% eating) occurred near noon and from midnight to dawn. The intensity of daytime intake activity was greatest in the Fan+SP barn, intermediate in the TP+SP barn, and lowest in the TP barn. In our previous study, the intake activity in the TP environment was 43% less after the p.m. feeding than that seen in the Fan+SP group (35.7 vs. 62.1%; $P < 0.05$; Shiao et al., 2009b). By increasing air speed and sprinkler cooling, the TP and TP+SP barns offered cows a more comfortable environment, increasing the intake activity of the p.m. main meal to 75 and 91% of that of the control group.

Rumen Digestion. The diet offered to all cows in this study consisted of 50% forage, 24% by-products, and 26% corn-soybean meal concentrate and contained 39% DM, 16.5% CP, 32.1% ADF, and 50.0% NDF (DM basis). Cows had similar intake activity and a similar rumen digestion pattern in this trial (Figure 5). The weighted averages of diurnal rumen pH were similar: 6.24, 6.12, and 6.20 for cows in the Fan+SP, TP, and TP+SP barns, respectively (Figure 5A). The highest rumen pH value of 6.47 was seen around 0700 h, just before the a.m. feeding. The lowest pH value (5.90) occurred approximately 5 h after the p.m. feeding, around 2000 h. The lowest NH_3-N level was higher in cows in the TP barn than in those in the Fan+SP barn (11.7 vs. 8.0 mg%; $P < 0.05$). The weighted diurnal average NH_3-N level of cows in the TP barn tended to be higher than that of cows in the other 2 barns (15.0 vs. 13.1 mg%; $P = 0.06$). The rumen NH_3-N level in this trial was relatively stable between 10 and 20 mg% (Figure 5B). Rumen total VFA production and individual VFA molar percentages were similar across the 3 barn treatments. The weighed rumen total VFA concentrations of cows in the Fan+SP, TP and TP+SP barns were 110, 112, and 104 m*M*, respectively (Figure 5C).

Lactation Performance. Cow BW was not affected by barn cooling treatments (Table 6). In 2005, the adverse environment in the TP barn decreased cow DMI by 7.6% (17.0 vs. 18.4 kg) and milk yield by 10.1% (4% FCM, 23.1 vs. 25.7 kg; $P < 0.001$; Shiao et al., 2009b). In the 2006 trial, the decremented DMI and milk yield problems had been resolved and even improved. The improved TP and TP+SP barns were associated with a small but significant increase in DMI relative to the Fan+SP barn (18.8 vs. 18.5 kg; $P < 0.05$; Table 6). The improved environment of both water-padded barns stimulated cow intake and resulted in higher milk yields. The milk yield of cows in the TP barn matched that of cows in the Fan+SP barn, and cows in the TP+SP barn produced 3% more milk than cows in the control barn (25.4 vs. 24.7 kg; $P = 0.10$). In this study, the low air speed at night in the water-padded barn contributed to cow heat stress. Although milk production was greatly improved in 2006 compared with 2005, we believe that further improvement is possible. Smith et al. (2006b) reported an 11%

increase in DMI and an increase of 2 kg of milk/cow per day. The milk protein concentration of cows in the TP+SP barn was lower than that of the other 2 groups, and the cause of this finding is not clear. The concentrations of milk fat, lactose, and total solids were not affected by barn cooling treatments. Smith et al. (2006b) reported that reducing heat stress would decrease SCC in raw milk. Their tunnel ventilation evaporative cooling decreased SCC by 27% compared with the Fan+SP barn. In the present study, the TP and TP+SP barns both improved cow udder health, indicating that the SCC in milk decreased substantially (43% and 54%, respectively; $P = 0.13$).

CONCLUSIONS

Increasing air speed and using sprinkler cooling significantly increased the potential efficacy and feasibility of the use of a TP+SP barn to alleviate cow heat stress in our hot and humid environment. Tunnel-ventilated, water-padded barns reduced daytime T more efficiently than did the Fan+SP barn. The high humidity found in a water-padded barn could be partially mitigated by increasing air speed. When daytime air speed increased from 1.66 to 2.38 m/s, cows in the TP and Fan+SP barns produced similar quantities of milk. When daytime air speed increased from 1.66 to 2.06 m/s in conjunction with sprinkling, cows in the TP+SP barn produced 3% more milk than cows in the Fan+SP barn. Research regarding further modification and evaluation of water-padded barns is continuing at LRI. The key contributors to improvement include sufficient air speed and sprinkler cooling.

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Table 1. Monthly average air temperature and relative humidity (mean ± SD) at the Livestock Research Institute of Taiwan from 2000 to 2009 (Meteorological Station B2N89)[1]

	Temperature, °C			Relative humidity, %		
Item	Mean[1]	Maximum[1]	Minimum[1]	Mean[1]	Maximum[1]	Minimum[1]
No.	60	60	60	60	60	60
Cool season[2]	20.2 ± 2.6	31.4 ± 2.2	10.6 ± 3.5	80.5 ± 3.6	99.4 ± 1.2	36.0 ± 8.1
Hot season[2]	27.1 ± 1.1	35.1 ± 1.2	21.1 ± 2.3	84.0 ± 3.5	99.9 ± 0.3	46.2 ± 8.9

[1] Mean data were calculated across days in a month. Maximum and minimum data were obtained by averaging the extreme data from each month.

[2] Cool season = November to April; hot season = May to October.

Table 2. Air speed (m/s; mean ± SD) in 3 experimental barns occupied by lactating Holstein cows in Taiwan during 2006[1]

		Barn[2]		
Time	Days measured	Fan+SP	TP	TP+SP
0830 h	15	1.18 ± 0.11	2.22 ± 0.60	1.80 ± 0.49
1330 h	16	1.23 ± 0.14	2.57 ± 0.27	2.23 ± 0.22
1630 h	16	1.29 ± 0.11	2.34 ± 0.37	2.13 ± 0.40
Average	15	1.23 ± 0.12	2.38 ± 0.45	2.06 ± 0.42

[1] Air speed was measured with a hot wire anemometer every Monday and Friday in 3 fully occupied barns from August to October, 2006. Values shown are averages of measurements taken at the front and back of each pen and from the TMR trough, intake lane, and alleyway between stall rows at 1.5 m elevation.

[2] Fan+SP barn = freestall barn with fans and sprinklers (control); TP barn = tunnel-ventilated, water-padded barn; TP+SP barn = TP barn with sprinklers.

Table 3. Effect of the tunnel-ventilated, water-padded barn environment on the diurnal vaginal temperature changes of lactating Holstein cows in Taiwan during 2006[1]

	Barn[2]				
Item	Fan+SP	TP	TP+SP	SEM	Significance
No. of cows	32	32	32		
Diurnal mean, °C	38.87[b]	39.08[a]	38.94[b]	0.04	**
Highest value (H),[3] °C	39.58	39.65	39.53	0.07	NS
Lowest value (L),[3] °C	38.16[b]	38.53[a]	38.07[b]	0.06	***
H - L, °C	1.43[a]	1.12[b]	1.45[a]	0.09	*

[a,b] Means within a row with different superscripts differ.

[1] Vaginal temperature was measured every minute using the HOBO Water Temp Pro Data Logger (Onset Computer Corp., Bourne, MA) fitted into a blank control internal drug release (CIDR, Eazi-Breed, Pfizer Animal Health, New York, NY) device and inserted into the cow's vagina for 24 h.

[2] Fan+SP barn = freestall barn with fans and sprinklers (control); TP barn = tunnel-ventilated, water-padded barn; TP+SP barn = TP barn with sprinklers.

[3] Mean data were analyzed from the daily averages of 32 cows in each group, and the highest and lowest values were the averages of daily extreme data.

NS = $P > 0.05$; * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$.

Table 4. Effect of the tunnel-ventilated, water-padded barn environment on blood gases and serum biochemical metabolites of lactating Holstein cows in Taiwan during 2006[1]

	Barn[3]				
Item[2]	Fan+SP	TP	TP+SP	SEM	Significance (P-value)
No. of cows	32	32	32		
Blood pH	7.405	7.397	7.404	0.003	0.08
pCO_2, mmHg	42.3	42.8	42.6	0.4	NS
pO_2, mmHg	31.5[a]	30.5[b]	30.4[b]	0.3	*
Total protein, g/L	69.5[b]	70.6[ab]	71.6[a]	0.5	*
Albumin, μmol/L	0.49	0.49	0.49	0.01	NS
BUN, mmol/L	7.28	7.56	7.40	0.11	NS
Ca, mmol/L	2.16	2.18	2.18	0.02	NS
P, mmol/L	1.94[b]	2.08[a]	1.95[b]	0.03	*
Glucose, mmol/L	2.34	2.28	2.34	0.05	NS
Cholesterol, mmol/L	6.47[a]	6.21[ab]	6.10[b]	0.09	*
ALP, U/L	43.5[a]	38.8[b]	41.4[ab]	1.0	**
AST, U/L	81.7	86.2	85.7	1.6	0.10
ALT, U/L	42.9[a]	40.6[b]	41.5[b]	0.4	***
LDH, U/L	672	690	693	19	NS

[a,b] Means within a row with different superscripts differ.

[1] Blood samples from each individual cow were taken twice at 1300 h from the jugular vein each period in a 3 × 3 Latin square design.

[2] pCO_2 = partial pressure of carbon dioxide; pO_2 = partial pressure of oxygen; ALP = alkaline phosphatase; AST = aspartate aminotransferase; ALT = alanine aminotransferase; LDH = lactate dehydrogenase.

[3] Fan+SP barn = freestall barn with fans and sprinklers (control); TP barn = tunnel-ventilated, water-padded barn; TP+SP barn = TP barn with sprinklers.

NS = $P > 0.05$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 5. Effect of the tunnel-ventilated, water-padded barn environment on the intake and resting activity of lactating Holstein cows in Taiwan during 2006[1]

	Barn[2]				
Item	Fan+SP	TP	TP+SP	SEM	Significance (*P*-value)
No. of observations	3	3	3		
Time spent lying, h/d	12.2	11.5	12.3	0.3	NS
Time spent eating, h/d	5.7	4.8	5.1	0.2	NS
Percentage of cows eating					
0730 to 0930 h (a.m. feeding)	53.9	42.9	47.7	6.4	NS
0930 to 1130 h	23.6	21.9	24.8	0.5	0.10
1130 to 1430 h	12.6[a]	6.3[b]	8.5[ab]	0.7	*
1500 to 1730 h (p.m. feeding)	67.7	50.7	61.3	3.1	0.11
1730 to 2100 h	21.0	22.1	23.8	2.2	NS
2100 to 0000 h	17.0	19.2	20.1	2.5	NS
0000 to 0500 h	9.8	11.2	7.2	0.8	NS
5000 to 0730 h	22.2	13.4	14.8	3.9	NS

[a,b] Means within a row with different superscripts differ.

[1] Thirty-six cows were randomly assigned into 3 barn treatments in a 3 × 3 Latin square design and group-fed. Two periods of 24 h of cow behavior were recorded by video and counted every 10 min. The percentage of cows eating was calculated from this data.

[2]Fan+SP barn = freestall barn with fans and sprinklers (control); TP barn = tunnel-ventilated, water-padded barn; TP+SP barn = TP barn with sprinklers.

NS = $P > 0.05$; * $P < 0.05$.

Table 6. Effect of the tunnel-ventilated, water-padded barn environment on the lactation performance of lactating Holstein cows in Taiwan during 2006[1]

Item	Barn[2]			SEM	Significance (*P*-value)
	Fan+SP	TP	TP+SP		
No. of observations	3	3	3		
DMI, kg	18.5[b]	18.8[a]	18.8[a]	0.03	*
No. of cows observed	32	32	32		
Initial BW, kg	546	549	549	2	NS
BW gain, kg/d	0.40	0.23	0.32	0.10	NS
Milk yield, kg/d	24.7	25.0	25.4	0.2	0.10
4% FCM, kg/d	24.9	25.1	25.4	0.3	NS
Milk fat, %	4.06	4.05	4.02	0.05	NS
Milk protein, %	3.18[a]	3.18[a]	3.11[b]	0.02	*
Milk lactose, %	4.74	4.73	4.75	0.02	NS
Milk total solid, %	12.67	12.67	12.58	0.05	NS
SCC, $\times 10^4$/mL	127	73	58	25	0.13

[a,b] Means within a row with different superscripts differ.

[1] Thirty-six cows were randomly assigned into 3 barn treatments in a 3 × 3 Latin square design and group-fed. Individual milk yields were recorded daily, and 2 a.m.-p.m. milk samples were taken for composition analyses per period. Thirty-two cows went through the trial.

[2]Fan+SP barn = freestall barn with fans and sprinklers (control); TP barn = tunnel-ventilated, water-padded barn; TP+SP barn = TP barn with sprinklers.

NS = $P > 0.05$; * $P < 0.05$.

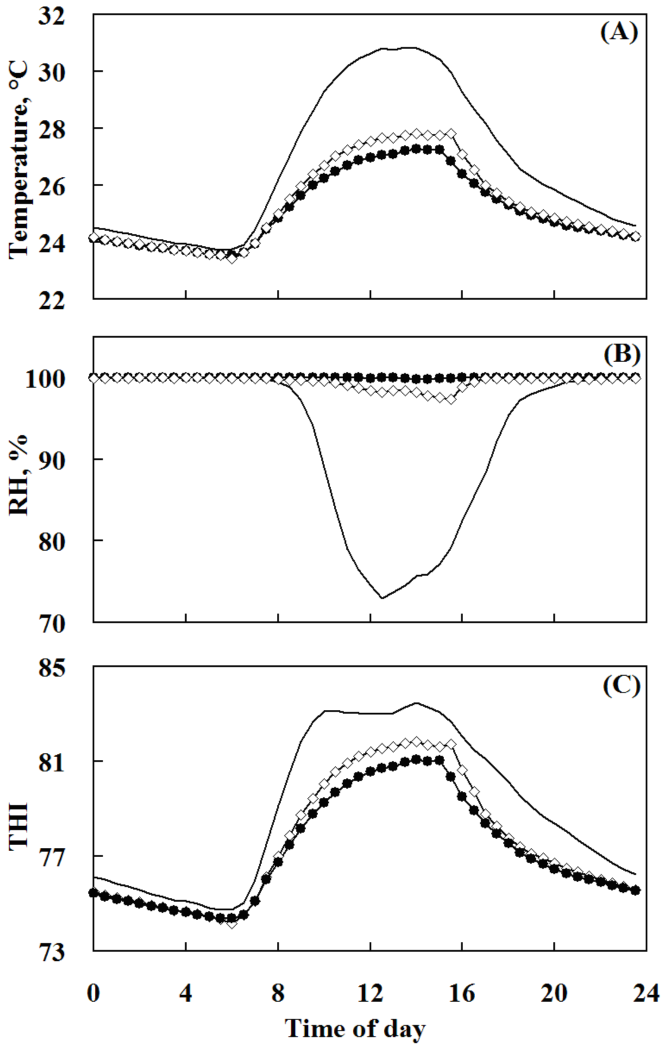

Figure 1. Effect of the tunnel-ventilated, water-padded barn environment on (A) barn diurnal temperature (T), (B) relative humidity (RH), and (C) temperature-humidity index (THI) changes. The barn environments compared included the Fan+SP barn (solid line; freestall barn with fans and sprinklers, control), TP barn (•; tunnel-ventilated, water-padded barn), and TP+SP barn (◊; TP barn with sprinklers) during the hot, humid season (August to October) at the Livestock Research Institute of Taiwan during 2006. Barn T and RH were recorded every 30 min by HOBO Pro RH/Temp meters (Onset Computer Corp., Bourne, MA). THI = $9/5 \times T + 32 - 0.55 \times (1 - RH) \times (9/5 \times T - 26)$, with T in ºC and RH in decimal (NOAA, 1976). Each point represents the average of 63 d daily measurements.

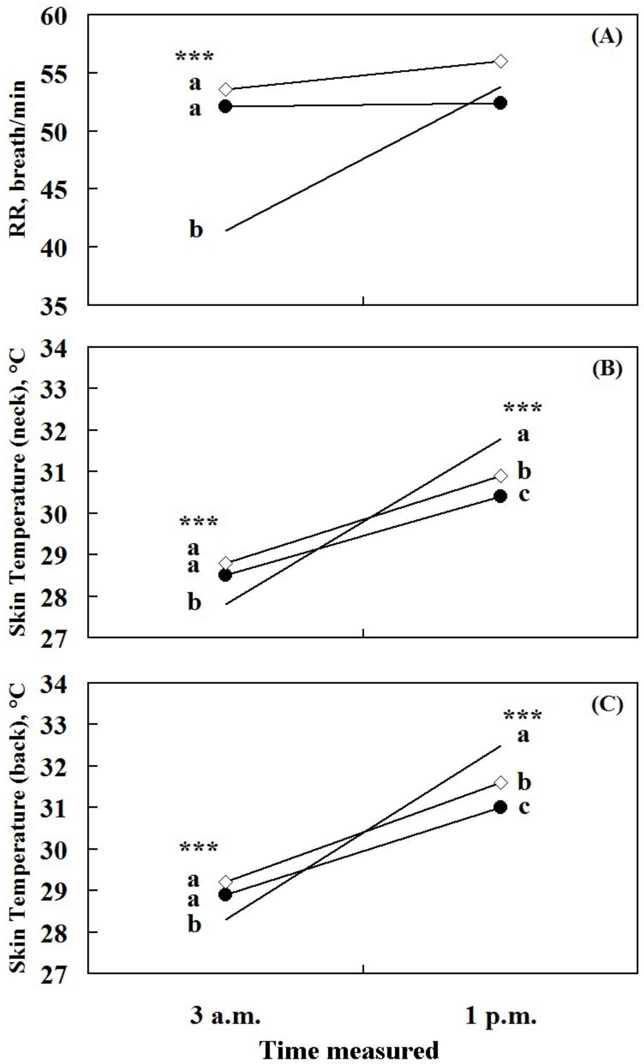

Figure 2. Effect of the tunnel-ventilated, water-padded barn environment on (A) respiration rates (RR) and skin temperature (T) of the neck (B) and back (C) of lactating Holstein cows. The RR and skin T were measured at 0300 and 1300 h on 2 d during the last 10 d of each period from 29 cows raised in the Fan+SP barn (solid line; freestall barn with fans and sprinklers, control), TP barn (•; tunnel-ventilated, water-padded barn), and TP+SP barn (◊; TP barn with sprinklers) in a 3 × 3 Latin square design. Cows raised in the TP and TP+SP barns had higher RR and neck and back skin T at 0300 h than those raised in the Fan+SP barn (*** $P < 0.001$). At 1300 h, the neck and back skin T differed among the 3 barn treatments. Data points with different characters, a, b, and c, differ (Fan+SP > TP+SP > TP barn, *** $P < 0.001$).

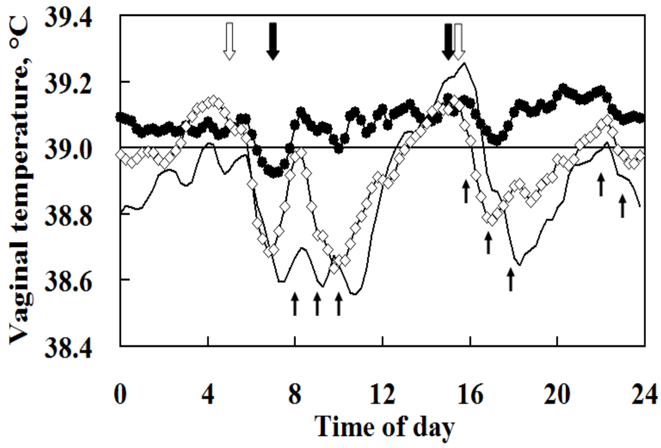

Figure 3. Effect of the tunnel-ventilated, water-padded barn environment on the diurnal vaginal temperature changes of lactating Holstein cows. Cows were raised in the Fan+SP barn (solid line; freestall barn with fans and sprinklers, control), TP barn (●; tunnel-ventilated, water-padded barn), and TP+SP barn (◊; TP barn with sprinklers) in a 3 × 3 Latin square design. Vaginal temperature was taken every minute by the Hobo Water Temp Pro Data Logger (Onset Computer Corp., Bourne, MA) fixed in a blank control internal drug release (CIDR, Eazi-Breed, Pfizer Animal Health, New York, NY) device and inserted into the vagina for 24 h. Milking (downward white arrow) and spray cooling (thin black arrows) effectively decreased the vaginal temperature of cows in the Fan+SP and TP+SP barns. The 2 feeding times are indicated by a downward black arrow. The vaginal t of cows in the TP barn decreased only after milking and to a much smaller degree. Each point represents an average of 32 cows per group.

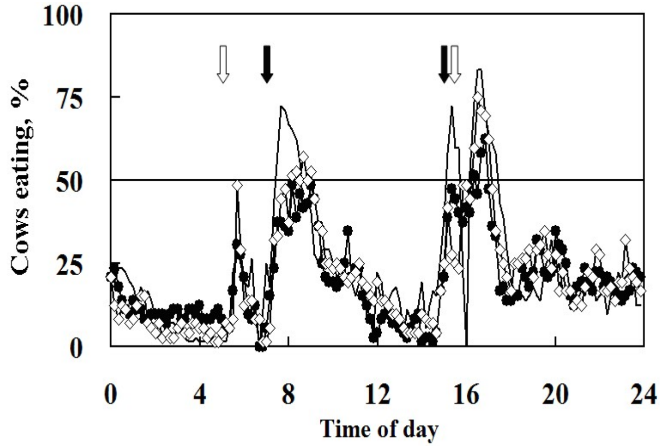

Figure 4. The effect of the tunnel-ventilated, water-padded barn environment on the intake activity of lactating Holstein cows. A total of 36 cows were group-fed in the Fan+SP barn (solid line; freestall barn with fans and sprinklers, control), TP barn (●; tunnel-ventilated, water-padded barn), and TP+SP barn (◊; TP barn with sprinklers) in a 3 × 3 Latin square design. Cow activity was recorded by video and counted every 10 min for two 24-h periods. The number of cows eating was calculated as the percentage of each group. The peak intake activity appeared soon after fresh TMR were offered (black arrows) and decreased to 0% when cows left for milking (white arrows).

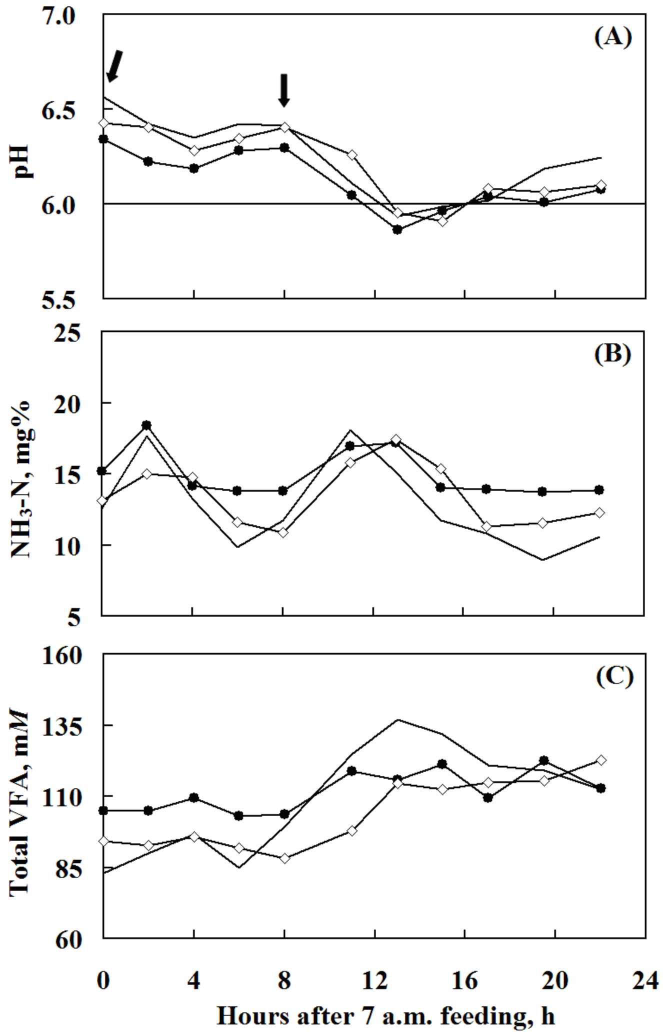

Figure 5. Effect of the tunnel-ventilated, water-padded barn environment on the diurnal rumen pH, NH_3-N and VFA concentrations of lactating Holstein cows. Three rumen-cannulated cows were raised in the Fan+SP barn (solid line; freestall barn with fans and sprinklers, control), TP barn (●; tunnel-ventilated, water-padded barn), and TP+SP barn (◊; TP barn with sprinklers) in a 3 × 3 Latin square design. Two consecutive 24-h rumen content samplings were conducted each period. Rumen digestion became active after 2 fresh TMR offerings (arrows). Rumen NH_3-N concentration was more stable and tended to be higher (P = 0.06) in cows raised in the TP barn. The diurnal weighted average, highest and lowest values of rumen pH and total VFA were similar among barn treatments