COLD WORKING ENVIRONMENTS ON DAIRY FARMS IN FINLAND

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ABSTRACT

Objectives. The study aimed to clarify in what kind of thermal environments agricultural work is done in Finland. The investigation focused on low temperatures and the working environments on dairy farms.
Methods. The approached was based on measurements of thermal environments in dairy barns and calf shelters, and weather data from 117 meteorological stations in Finland. The interdependence between the indoor temperatures and the weather was studied with the help of mathematical models.
Results. Mathematical prediction models for air temperature in various work-places on a farm were determined and air velocity measured. Farmers are exposed to a wide range of temperatures on a daily basis. The range is widest on farms having insulated barns and long work periods with a tractor. There is frosty weather during 3-6 months per year. The air velocity is normally fairly low.
Conclusions. The main problem in the working environments on a farm relating to thermal conditions is the wide temperature range of the various work-places occupied during a work cycle. Knowledge of thermal environments should be taken into consideration when planning work-places and when planning work sequences, their order and methods of working, and the division of labour between farm workers.

Keywords: Farm work, Working environment, Outside work, Uninsulated buildings.

INTRODUCTION

Finland is one of the most northern countries in which agriculture is practiced (the mainland lies between 59°48'30" N and 70°5'30" N). Agricultural work is carried out in buildings, outside in fields and yards, and in the cabins of farm machinery. The air temperature can be below recommendations in all of these places; the same is true for cattle houses, which may not be insulated.

There is no generally accepted definition of cold work. Work can, however, be considered as a cold work if the thermal environment, and particularly the air temperature, does not reach the lowest levels recommended for indoor working environments. In Finland, the lowest recommended temperature is +18 °C for light work, +15 °C for moderate work, and +10 °C for heavy work (1). A cold environment can be defined as "an environment under which greater than normal heat losses are anticipated and compensatory thermoregulatory actions are required" (2). Because of the northern location of the country, all jobs requiring work outside - including agriculture - involve at least some cold work. In Finland, about 25 % of the labour force has experienced at least some problems with cold (3).

Occupational cold exposure can cause thermal discomfort and, with excessive heat loss, pain sensation (4). Cold may also impair fine movements, especially of the fingers and hands (5), as well as muscle function by deprivation of sensory functions and the slowing of metabolic processes (2, 6), thus restricting performance and work capacity. Inhalation of very cold air can lead to adverse respiratory effects (7) like irritation, micro-inflammatory reactions and bronchospasm (2). The cold environment may also have significant cardiovascular effects, e.g. it causes increased blood pressure by reducing the blood flow in vessels and by increasing the viscosity of the blood (8). The cardiovascular effects may even interfere with the actions of some drugs that elicit thermoregulatory responses (2). Of course, there is also a risk of cold injury in cold environments: local freezing with frostnip, or frostbite, or general body cooling, and even hypothermia if the body temperature drops below 35 °C (6). The use of protective measures to prevent cooling can increase the physical workload (hobbling effect) and prolong performance times (9).

There are several reasons which make the study of cold work in agriculture important. Farmers still comprise the largest occupational group in Finland exposed to temperatures below -10 °C (3); there are new findings concerning the effects of cold on human health and performance (2, 6, 10); chronic diseases are more common among farmers than among other workers - especially among female farmers (11); the mean age of farmers is getting higher and, at least among men, thermoregulatory adjustments become less efficient with ageing (12). The importance of cold work has increased, because the relative importance of animal husbandry has increased since Finland joined the EU. Farms continuing production are enlarging, which means longer working hours. At the same time, farmers are seeking more economic solutions, like uninsulated buildings for cattle. As for the cold exposure of Finnish farmers, it must be remembered that, on most farms, there is also a significant amount of forestry work done.

During the last decade uninsulated loose housing barns have become common also on farms with dairy cattle - not only with beef cattle. Production on farms has been planned according to economical calculations and the full usage of the labour of the family. The production environment has been designed according to biological processes, animals, forages, and products. Little attention has been paid to the working environment - and little information is available concerning its improvement. Thermal environments have, however, been investigated also in uninsulated barns (13, 14, 15, 16, 17). The temperature in the animal hall has been found to be only few degrees higher than the temperature outside the barn. During wintertime, when the outside temperature is -10.0 °C, the difference between outside and inside temperatures is, on average, about 6 °C (13, 14), and the difference increases as the weather gets colder. In an uninsulated building with a transparent roof, solar radiation can raise the temperature difference by several degrees in latitudes corresponding to southern Sweden (16). There is no literature available concerning series of temperature measurements made over a period of several days in other rooms of barns, such as milking parlours.

The aim of this study was to investigate in what kind of cold thermal environments agricultural work is done in Finland and how indoor temperatures in various work-places on dairy farms depend on the outdoor temperature. All the typical production environments in dairy farming were studied, including outfields, buildings and tractor cabins. Knowledge of thermal environments in agricultural work forms the basis for the prospective investigation of thermal stress in agriculture and provides a guide for reducing thermal problems.

MATERIAL AND METHODS

In this study, two climatic factors, air temperature and air velocity, were studied. Humidity, however, was excluded, because the water content of air is very small at low temperatures and its influence on cold stress is thus minor. For example, the effect of a change in relative humidity from 10 % to 90 % on the clothing insulation required corresponds to that of a temperature change of -0.5 °C at the -5 °C level, and of -0.2 °C at the -20 °C level (metabolic rate 190 W/m^2), calculated using the analytical IREQ (*Insulation reqired*) index (18) of cold stress. Thus, when applying IREQ, a relative humidity of 50 % can be assumed at sub-zero temperatures (18).

Data on the Finnish weather and its variations over a period of three years (1998 - 2000) were collected from the statistics of the Finnish Meteorological Institute. The data is from 117 Weather and Climate Stations all around Finland, from Hanko to Utsjoki, and thus covers the whole farming area of Finland. It comprises average, minimum and maximum daily values of air temperature, and wind velocity.

In order to define temperature and wind velocity distributions, some values were interpolated into "holes" (missing values) in the data. If more than five consecutive values were missing, the whole annual data from that meteorological station was rejected. The impact of the interpolation was in all cases less than 0.19 °C on the mean daily temperature of a year (compared with the original data with "holes"), which is a fraction of the annual standard deviation of the mean daily temperature. For wind velocity, the impact of the interpolation was even less significant: in all cases less than 0.01 m/s on the mean daily wind velocity of a year. At most, 19 temperature values (5.2 % of the values) and three wind velocity values (0.8 %) were interpolated into the annual data. However, the parameters which are presented in this work have been calculated using the data from three years (instead of one year), and thus the impact of the interpolation on the results is minor.

Besides the weather and climate stations, weather results were also calculated regionally for various Labour and Trade Centres (TE Centres, joint service centres of administrative branches of the Ministry of Trade and Industry, the Ministry of Agriculture and Forestry and the Ministry of Labour situated in 15 localities) of Finland (Figure 1). The number of cold days ($t < 0$ °C, $t < -10$ °C and

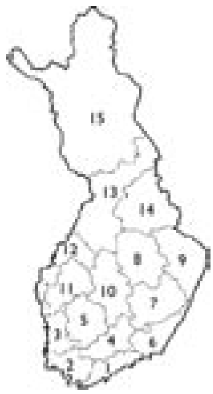


Fig 1. Labour and Trade Centres (TE Centres) in Finland.

t < -20 ^{o}C) and percentiles 10 %, 50 %, and 90 % of wind velocity in each region were determined.

Conditions in various buildings and rooms were measured in two types of cold loose housings barns - open and closed barns - in 1993 - 1994, in a traditional barn and insulated and uninsulated shelters for calves in 1997 - 1999, and on a research farm with both insulated and uninsulated loose housing barns in 1999 - 2000. Measurements were carried out in these five dairy barns and two calf shelters over a total period of 878 days. Temperatures in tractor cabins were determined according to the measurements performed by MTT Agrifood Research Finland, Agricultural Engineering Research (Vakola). Seven tractor cabins were tested in heater tests in 1989 - 1994.

In 1993 and 1994, temperatures were measured in the various rooms of two types of uninsulated dairy barn: in an open barn for 68 cows and in a closed barn for 40 cows - both loose housing barns with cubicles - using two-terminal integrated circuit temperature transducers (AD 590) installed at a height of 1.2 m. There were 23 temperature sensors in the open barn and 30 in the closed barn. On both farms, measurements were made every five minutes during four two-week periods: in summer, autumn, winter and spring. In all, measurements were made on 111 days. During autumn, winter and spring wind velocity, direction of wind (by Vaisala Anemometer WAA 12 and Vaisala Wind Vane WAV 12), and air velocity inside both barns (by Wallac^{TM} and Testo 452^{TM}) were also measured. The measurements inside the barns were made manually 24 - 40 times per animal hall, or milking parlour, at heights of 0.1 m, 1.2 m, and 1.8 m during the whole measuring period.

While rearing dairy calves in the traditional barn and outside in two shelters - one thermoregulated and the other non-thermoregulated - temperatures were measured from September 1997 to March 1999 (altogether on 403 days; not during the summers), every 15 minutes at heights of 0.2, 0.8, and 2.0 m. AD 590 IC temperature transducers were used. Because the temperature sensor outdoors was damaged in autumn 1998, other outside temperature values were estimated on the basis of temperatures measured at the greenhouse of the Viikki Campus Area, about 600 m from the shelters.

Temperatures were also measured in two loose housing barns in 1999 - 2000. There were six sensors (T-type thermocouples) in the uninsulated barn for 51 cows and two sensors in the insulated barn for 50 cows, located at a height of 2.3 m. Measurements were made every 15 minutes for one year (altogether 364 days, from 1 October 1999 to 30 September 2000).

Linear and non-linear regression analyses were performed using the outdoor temperature, or the wind velocity, as explanatory variables, and the indoor temperature, or air velocity, as dependent variables. SPSS for Windows and MS Excel programmes were used.

RESULTS

Regression models (Eq. 1 - 7) were calculated on the basis of temperature measurements. On the basis of these, prediction models (Eq. 8 - 11) for air temperature in various work-places on a farm were defined. The variation of air velocity and the number of annual frosty days were also determined. Finally, the prediction models and weather data were combined in order to show the temperature variations in various work-places and regions of the country.

Temperature

In Finland there is frosty weather (daily average below 0 °C) during 3 - 6 months of the year, depending on the location (Figure 2). The number of frosty days is lowest in the south-west (Varsinais-Suomi) and highest in the north (Lapland) (Table I). The mean daily temperature during the coldest day in a given year varies widely: from -18.9 °C (Varsinais-Suomi) to -35.9 °C (Lapland) and the momentary air temperature can even be below -40 °C.

During the measurements on farms, outside temperatures varied between -27.5 and 29.4 °C. The results of the investigation on farms

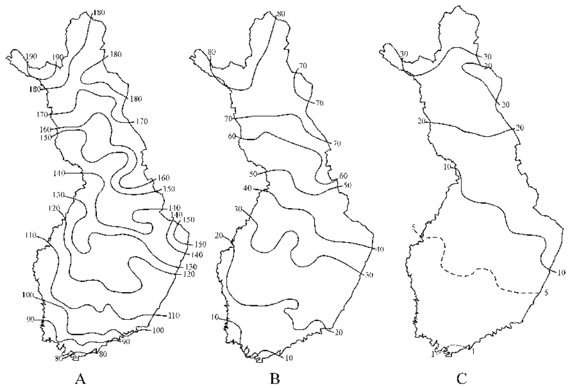


Fig 2. Number of annual A: frosty days (mean daily air temperature <0°C), B: days below -10°C and C: days below -20°C in Finland in 1998 - 2000.

can be summarized in the form of regression models and squares of regression coefficients (R^2). The temperature in an uninsulated barn (Equations 1 and 2 from measurements in 1993 - 1994, Equation 3 from measurements in 1999 - 2000) and in an insulated barn (Equation 4 from measurements in 1999 - 2000, Equation 5 from 1997 - 1999) was found to depend on the outside temperature as follows:

(Eq. 1) $t_{(open\ barn)} = 2.53 + 0.909 \times t_{(outside)}$ $R^2 = 0.971$

(Eq. 2) $t_{(closed\ barn)} = 2.30 + 0.859 \times t_{(outside)}$ $R^2 = 0.975$

(Eq. 3) $t_{(open\ barn)} = 1.46 + 0.957 \times t_{(outside)}$ $R^2 = 0.995$

(Eq. 4) $t_{(insulated\ barn)} = 5.67 + 5.55 \times EXP(0.0542 \times t_{(outside)})$ $R^2 = 0.972$

(Eq. 5) $t_{(traditional\ barn)} = 7.47 + 4.52 \times EXP(0.0706 \times t_{(outside)})$ $R^2 = 0.601$

Regression models for the non-thermoregulated (6) and thermoregulated (7) calf shelters are shown below. The thermoregulated shelter turned out to be neither cold, nor warm: the air temperature is somewhere between that of an insulated and uninsulated barn.

Table I. Mean number of cold days per year (according to daily averages and the lowest momentary daily values) and mean daily minimum temperatures (Tmin: daily averages and the lowest momentary daily values) recorded by various Labour and Trade Centres (TE Centres) in Finland during 1998 - 2000.

	Number (n) of						Tmin (°C)	
	Days below 0°C		Days below -10°C		Days below -20°C			
TE Centre	Aver.	Lowest	Aver.	Lowest	Aver.	Lowest	Aver.	Lowest
Uusimaa	91.4	137.0	12.8	33.3	1.7	6.3	-19.3	-24.5
Varsinais-Suomi	88.0	133.8	11.1	26.9	1.4	4.6	-18.9	-24.2
Satakunta	104.8	152.2	18.3	42.6	2.5	8.6	-21.5	-26.8
Häme	107.6	154.6	20.1	44.8	3.4	10.2	-22.5	-28.5
Pirkanmaa	115.0	158.0	21.0	46.5	3.1	10.7	-22.9	-27.9
Kaakkois-Suomi	106.6	146.6	20.3	40.8	2.9	9.4	-21.2	-26.2
Etelä-Savo	118.4	158.3	26.8	47.8	5.6	12.8	-23.4	-28.6
Pohjois-Savo	130.1	172.1	34.0	61.7	8.8	19.5	-26.0	-31.7
Pohjois-Karjala	138.2	176.8	41.9	70.5	12.6	26.7	-27.8	-33.0
Keski-Suomi	125.4	167.4	27.8	54.3	5.4	14.3	-24.8	-30.5
Etelä-Pohjanmaa	119.4	174.1	27.6	56.4	4.4	13.2	-23.6	-29.0
Pohjanmaa	112.5	153.8	23.0	49.0	4.1	9.8	-22.5	-28.2
Pohjois-Pohjanmaa	142.1	188.8	46.9	77.5	13.4	31.0	-30.4	-33.9
Kainuu	148.5	188.6	48.4	79.1	13.2	28.3	-31.4	-34.7
Lappi	169.8	218.4	71.7	109.8	23.3	52.8	-35.9	-40.7

(Eq. 6) $t_{(\text{cold shelter})} = 1.42 + 0.963 \times t_{(\text{outside})}$ $R^2 = 0.938$

(Eq. 7) $t_{(\text{thermoregulated shelter})} = -197.26 + 207.72 \times \text{EXP}(0.00299 \times t_{(\text{outside})})$ $R^2 = 0.569$

The prediction model for air temperature in uninsulated (loose housing) buildings for bovines (Equation 8) was derived from the regression models introduced in Equations 1 - 3 and 6 by using the results of these four models as input data into a regression analysis.

(Eq. 8) $t_{(\text{uninsulated})} = 1.92 + 0.921 \times t_{(\text{outside})}$ $R^2 = 0.997$

In insulated barns for dairy cows (with either loose housing, or a tied stall system), the air temperature correlates non-linearly with the outside temperature according to the prediction model (Equation 9) derived from regression Equations 4 and 5.

(Eq. 9) $t_{(\text{insulated})} = 5.96 + 5.85 \times \text{EXP}(0.0534 \times t_{(\text{outside})})$ $R^2 = 0.975$

The temperature in the milking parlour of an uninsulated barn (Equations 10 and 11) is somewhat lower than that in the milking parlour of an insulated barn during frosty weather. That is because, in an insulated barn, the milking parlour is normally part of the same airspace as the animal hall, and the animals continually produce substantial amounts of heat. In a cold barn, the animals just visit the milking parlour, which is separate from the animal hall.

(Eq. 10) $t_{(autotandem)} = 9.77 + 0.283 \times t_{(outside)} + EXP(0.0941 \times t_{(outside)})$ $R^2 = 0.958$

(Eq. 11) $t_{(herringbone)} = -2.68 + 13.76 \times EXP(0.0232 \times t_{(outside)})$ $R^2 = 0.957$

As expected, variations in outdoor temperature explained over 95 % of the variation in indoor temperatures in uninsulated barns. In the traditional barn and thermoregulated shelter, only 60 % of the variation in indoor temperature was explained by outdoor temperatures.

The temperature in a tractor cabin reached ±0 °C in an average of 9 minutes, and +10 °C within 15 minutes, when the outdoor temperature was in the range of -14.6 to -18.7 °C. The differences in warming-up times between cabins were great (Figure 3). In a dairy

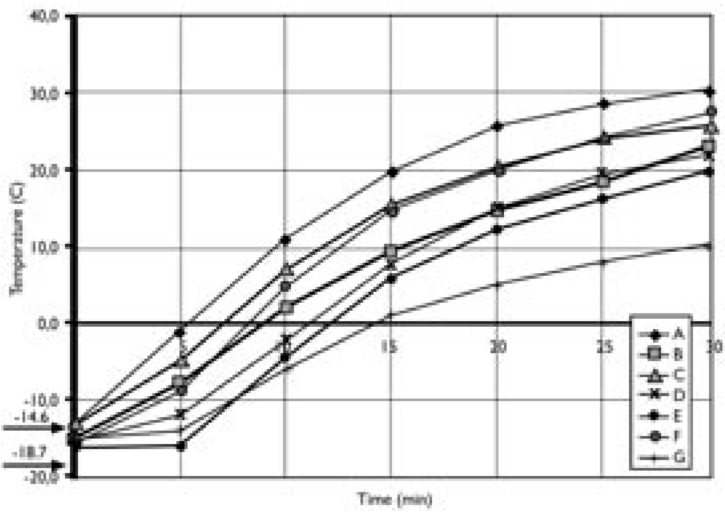
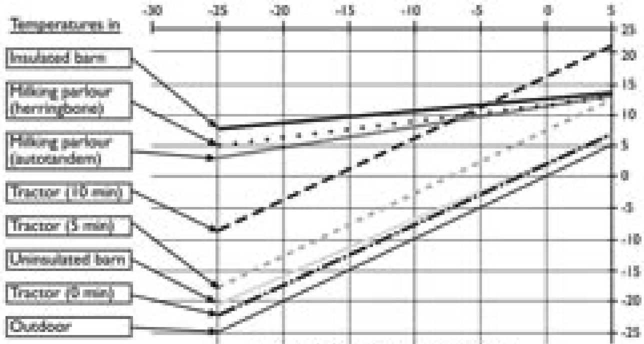


Fig 3. Warming-up of tractor cabins (A - G) tested in Agrifood Research Finland 1989 - 1994. The outdoor temperature was between -14.6 and -18.7°C at the beginning of tests.



DAYS PER YEAR ON AVARAGE

Uusimaa	<1	1	3	8	25	53	78
Varsinais-Suomi	<1	1	2	7	21	56	77
Satakunta	1	2	4	12	30	57	74
Häme	1	2	4	12	32	55	72
Pirkanmaa	1	3	5	13	34	60	69
Kaakkois-Suomi	1	2	5	13	29	57	71
Etelä-Savo	1	4	6	15	36	56	69
Pohjois-Savo	3	6	9	17	40	57	66
Pohjois-Karjala	4	8	8	21	39	58	63
Keski-Suomi	2	4	7	15	38	59	67
Etelä-Pohjanmaa	1	3	6	17	38	54	72
Pohjanmaa	1	3	4	15	35	55	72
Pohjois-Pohjanmaa	5	8	13	21	40	56	67
Kainuu	6	7	11	24	42	58	63
Lappi	11	12	20	28	41	57	66

Fig 4. The dependence of temperatures in various workplaces in a farm on the outdoor temperature and the approximate number of days per temperature range recorded by various Labour and Trade Centres (TE Centres) of Finland.

farm with an uninsulated barn, daily work periods with a tractor are fairly short: feeding operations take less than ten minutes and mucking operations about half an hour (19). In some operations the cabin doors are frequently opened, resulting in considerable fluctuations of the cabin temperature.

The comparison of the temperatures calculated according to Equations 8 - 11 with the actual measurements made on farms (n=11) independently of the temperature models, reveals that the error in predicted temperatures in the barn and milking parlour is on the average less than 2.0 °C (variation 0.2 - 3.9 °C).

The temperature in the working environments on a farm can vary considerably, even during a given workday (Figure 4). The range is larger as the weather gets colder, and is even greater with an insulated barn and long work periods with a tractor. On average (with an insulated barn), the daily temperature range is more than 15 °C during about 4 months (outdoor temperature < 0 °C), more than 20 °C during one month (outdoor temperature < -10 °C) and more than 30 °C during one week (outdoor temperature < -20 °C) for any given year.

Table II. P10, P50 and P90 values (according to daily averages and the highest momentary daily values) of wind velocity and daily maximum velocities (Windmax; daily averages and the highest momentary daily values) recorded by various Labour and Trade Centres (TE Centres) in Finland during 1998 - 2000.

	Wind velocity (m/s)						Windmax (m/s)	
	P10 %		P50 %		P90 %			
TE Centre	Aver.	Highest	Aver.	Highest	Aver.	Highest	Aver.	Highest
Uusimaa	1.5	2.7	2.9	4.6	5.0	7.3	9.0	12.5
Varsinais-Suomi	1.1	2.0	2.2	3.7	4.1	5.8	7.7	10.8
Satakunta	1.4	2.4	2.7	4.4	4.6	6.8	7.3	11.6
Häme	0.9	1.6	2.1	3.4	4.1	5.9	6.9	9.7
Pirkanmaa	1.0	1.9	2.3	3.4	4.0	5.7	6.6	9.1
Kaakkois-Suomi	1.9	3.0	3.6	5.3	6.3	8.7	10.8	13.6
Etelä-Savo	1.6	2.5	2.8	3.8	4.6	6.1	8.0	10.7
Pohjois-Savo	1.2	2.0	2.5	3.8	4.4	6.1	7.5	10.4
Pohjois-Karjala	1.0	1.7	2.2	3.0	4.1	5.7	6.8	9.0
Keski-Suomi	1.2	2.1	2.4	3.7	4.2	6.3	6.6	10.2
Etelä-Pohjanmaa	1.1	2.0	2.4	3.8	4.4	6.7	7.1	10.6
Pohjanmaa	1.5	2.9	3.2	5.1	6.2	9.3	10.1	14.4
Pohjois-Pohjanmaa	1.2	1.9	2.6	4.0	4.6	6.4	7.7	11.1
Kainuu	1.0	1.6	2.4	3.5	4.2	5.8	7.2	9.4
Lappi	0.7	1.4	2.2	3.6	4.3	6.2	8.1	11.2

Air velocity

Wind velocity is normally fairly low in Finland; in 1998 – 2000, the daily median value was 2.1 - 3.6 m/s, depending on the area (Table II). No clear systematic regional order could be seen, except that the highest velocities were measured in the coastal towns of Kotka, Hanko, and Vaasa. The position of the measurements imposed, for example, by the topography of the area, may have had the most effect on the measured values. In any case, the wind velocity in a farmyard is also affected by the presence of buildings, trees and other obstacles.

The air velocity measured inside the uninsulated barns were, on average, 0.2 - 0.6 m/s in animal halls and 0.1 - 0.3 m/s in milking parlours (Table III). The mean air velocity was, to some degree, higher in the open animal hall than in the closed hall and, in the milking

Table III. Average air velocity (m/s), measured at various heights above ground, in the milking parlour and animal hall of the open and closed uninsulated loose housing dairy barn.

	Air velocity (m/s)			Number of
Room	10 cm	120 cm	180 cm	**measurements**
Animal hall				
- open	0.6	0.6	0.6	3 x 40
- closed	0.4	0.3	0.2	3 x 27
Milking parlour				
- auto-tandem	0.3	0.2	0.2	3 x 24
- herringbone	0.2	0.1	0.1	3 x 27

parlour, it was highest at the lowest measuring height. The highest momentary values were 2.5 m/s in animal halls and 0.9 m/s in milking parlours.

There was no correlation between the wind velocity and the air velocity inside the buildings. Nor could the combined factors of the outside wind direction and velocity explain the variations in the inside air velocity.

The wind has an effect on the temperature difference between the outside and the inside of the uninsulated barn if the barn is open, i.e. has only three walls ($r = -0.761$, $\alpha = 0.1$ %), but not if the barn is closed ($r = -0.133$, ns). This means that, during windy weather, the temperature in an open uninsulated barn is slightly lower, and closer to the outside temperature, than in a closed uninsulated barn.

DISCUSSION

The cooling power of the working environment is determined by the combined effect of climatic factors - air temperature, air velocity, mean radiant temperature, and humidity - and the activity level of the worker (20). This study describes the variation of two of these essential factors, air temperature and air velocity, in Finnish agricultural working environments. The results are given for various working environments of farms and various regions of the country (Labour and Trade Centres). This is the first time this kind of account has been produced for the whole country. Using these results, it is possible to assess conditions and, in particular, their variations with time and place, but not to determine cold stress - for that, the metabolic heat production should also be known.

In an earlier study (13), it was found that the temperature differences between the outside and the inside of a barn are inversely related to the outside temperature. The difference is wider the less insulated the building is. This physical fact was observed also in this study. It was also noticed earlier (13) that, in addition to the outside temperature and wind speed, the general “tightness” of the building and the size of the door-opening have an effect on the temperature difference. In this study, the effect of wind speed on the temperature difference was only observed in the case of an open barn. This may be the result of the low wind velocities in Finland. However, the results of this investigation can also be used for other countries with similar types of farming conditions and weather. The validity of the prediction models is good when the outside temperature is not lower than -27 °C (-22 °C with Equation 11).

The main problems in working environments on a farm relating to thermal conditions are the large temperature fluctuations encountered in and between the various work-places occupied during a work cycle. This makes it difficult to dress appropriately and leads easily to both excessive and insufficient thermal clothing insulation. The results of this study provide knowledge of thermal environments which should be taken into consideration, not only when planning work-places, but also when planning work schedules, including their order and work methods to be employed, and the division of labour between farm workers. Because of the large temperature variations, various solutions must be envisaged.

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REFERENCES

1. Hassi J. Working in cold conditions. Ergonomiska mätmetoder i lantbruket. Kuopio regioninstitut för arbetshygien. Kuopio: Jord- och skogsbruksbyrå, 1983: 36—138.
2. Holmér I. Cold stress: Part I - Guidelines for the practitioner. In: Mital A, Kilbom Å, Kumar S (eds). Ergonomics Guidelines and Problem Solving. Amsterdam: Elsevier Ergonomics Book Series, 2000;1: 347—356.
3. Anttonen H. Exposure to physical factors - cold. (Altistuminen fysikaalisille tekijöille - kylmä). In: Kauppinen T, Heikkilä, P, Lehtinen S, Lindström K, Näyhä S, Seppälä A et al. (eds). Työ ja Terveys Suomessa v. 2000. Helsinki: Työterveyslaitos, 2000:42—43.
4. Fanger PO. Thermal Comfort - Analysis and Applications in Environmental Engineering. McGraw-Hill Book Company, 1970.
5. Enander AE, Hygge S. Thermal stress and human performance. Scand J Work Environ Health 1990;16,1: 44—50.
6. Holmér I. Cold stress: Part II - The scientific basis (knowledge base) for the guide. In: Mital A, Kilbom Å, Kumar S (eds). Ergonomics Guidelines and Problem Solving. Amsterdam: Elsevier Ergonomics Book Series, 2000;1:357—365.
7. O'Cain CF, Dowling NB, Slutsky AS, Hensley MJ, Strohl KP, McFadden ER Jr, et al. Airway effects of respiratory heat loss in normal subjects. J Appl Physiol 1980;49,5: 875—880.
8. Burton AC, Edholm OG. Man in a Cold Environment - Physiological and Pathological Effects of Exposure to Low Temperatures. New York: Hafner Publishing Company, 1969.
9. Rodahl K. Working in the cold. Arct Med Res 1991;50, Suppl. 6:80—82.
10. Oksa J. Cooling and neuromuscular performance in man. University of Jyväskylä. Studies in Sport, Physical Education and Health 1998;53:1—61.
11. Perkiö-Mäkelä M. Exercise- and ergonomics-focused promotion of health and work ability in farmers' occupational health services. Kuopio University Publications D, Medical Sciences 2000;223:1—93.
12. Wagner JA, Horvath SM. Influences of age and gender on human thermoregulatory responses to cold exposures. J Appl Physiol 1985;58,1:180—186.
13. Kammel DW, Cramer CO, Converse JC, Barrington GP. Thermal environment of insulated, naturally ventilated dairy barns. Livestock Environment 2. Proceedings of the Second International Livestock Environment Symposium. April 20—23, 1982, Scheman Center, Iowa State University. ASAE Publication 1982;3:62—71.
14. Holmerud JO. The research of the climate in an uninsulated building for milk production, winter 1991. (Klimaundersøkelse i uisolert bygning for melkekuer, vinteren 1991). NLH, ITF-notat 1991;82:1—7.
15. Holmerud JO, Storeheier KJ. Energy consumption and indoor climate in an uninsulated building for milk production. (Energiforbruk og klima i uisolert bygning for melkeproduksjon). NLH, ITF rapport 1994;56:1—74.
16. Jeppsson K-H, Gustafsson G. Solar heat load in uninsulated livestock buildings. J Agric Engng Res 2001;78,2: 187—197.
17. Gavhed D, Fredriksson K, Kuklane K, Holmér I, Norén O. Work in dairy-farms during the cold season - Survey and field study of the thermal environment. (Arbete i kyla mjölkproduktionsanläggningar - kartläggning och studie av termiska arbetsmiljöproblem). JTI-rapport 2002;290:1—86.
18. Holmér I. Assessment of cold stress in terms of required clothing insulation - IREQ. Int J Industr Ergon 1988;3,2:159—166.
19. Tuure V-M. Working environment in cold loose housing barns. (Työympäristö kylmissä pihatoissa). Helsingin yliopisto, maa- ja kotitalousteknologian laitos. Maatalousteknologian julkaisuja 1995;18:1—143.
20. Holmér I. Assessment of cold stress. Arct Med Res 1991;50, Suppl. 6:83—88.

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