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FEASIBILITY OF USING HEAT-RECOVERY EXCHANGERS IN LIVESTOCK BUILDINGS AT A SITE AT A SPECIFIC ALTITUDE WITH A SPECIFIC AVERAGE OUTDOOR AIR TEMPERATURE

The installation of an energy-saving facility must be preceded by analysis of its financial effectiveness. Among methods enabling such evaluation is the basic net profit calculation method. For this, the annual consumption of electricity for ventilation or of thermal energy for heating must be determined. The calculation formula uses the sum of energies for temperatures within the range from the calculation temperature for the area in question to the long-term average of the maximum temperature at the site, or to the temperature at which the heating power is zero. It is necessary to know the summary time of occurrence of a given temperature during a year. The site data can only be assessed based on long-term meteorological information. In fact, data used by current national standards to describe climatic conditions in the Czech Republic are from the years 1901 to 1950.

The dependence of the average yearly temperature on altitude is shown in Fig. 1 for the 1961 – 1990 and 1991 – 2000 periods. It is evident that the average temperatures for the latter period are nearly 0.6 K higher than those for the former period, irrespective of the altitude.

In this paper the climatic conditions are assessed based on daily data measured throughout the period from 1 January 1991 to 31 December 2000. Weather stations were selected so as to achieve a uniform coverage and continuity of measurement at each site (as far as possible). All the stations lie in the Czech Republic between 48.8° and 50.8° north latitude at altitudes from 158 m to 1324 m. It was the objective of this examination, based on the meteorological data collected to calculate the average number of days and hours during which the temperature during the year is lower than a specific limiting level, in dependence on the average yearly temperature of the site.

Fig. 3 shows the average number of days in a year during which a temperature lower than a selected limiting level occurs, as calculated for the 1991 – 2000 period. The results are presented for 4 areas with average yearly temperatures of 6 °C – 7 °C, 7 °C – 8 °C, 8 °C – 9 °C, and 9 °C – 10 °C, respectively. The graphs enables us to ascertain the number of days during which a heating facility is in operation if the facility is activated by outdoor air temperature decrease to below a specific limiting level.

If a typical daily temperature wave is considered, the method makes it possible to estimate the number of hours during which the air temperature is lower than the limiting level chosen. The difference between the data for various limiting levels allows us, for an area with a specific average yearly temperature to ascertain the time of occurrence of outdoor temperature within various ranges. The results of calculations are shown in Fig. 4 and Table 1.

The method applied enables underlying data to be prepared for the assessment of energy demands for air heating at a given site and for estimation of the energy savings that could be achieved by installing economical air heating facilities in livestock buildings.

INTRODUCTION

Agriculture was an energy-independent branch of national economy till the 19^{th} century. This situation changed with the advent of motorization in the 20^{th} century, when the consumption of fossil fuels and electricity started to increase. This was due to the change which occurred in the form of energy used. Biomass, which had been used before, was superseded by petroleum products, coal, and eventually also by electricity and gas.

Biofuels began to enjoy renaissance at the turn of the 20^{th} century and at the beginning of the 21^{st} century. Biofuels serve to satisfy energy needs not only in agriculture. Views upon the production of biofuels on arable land have been changing. Recent considerations regarding the size of the area of land that might be used for growing crops to serve as fuels has affected the global foodstuff price increases appreciably.

No rapid decrease in the consumption of fossil fuels or even independence of fossil fuels can be expected in agriculture in the nearest future. The trend will be towards the deployment of energy-saving technologies and use of renewable and secondary energy sources. Many of them have been developed theoretically and are being tested on the industrial scale. Among examples of energy recovery in agriculture are the use of heat recovered from freshly milk to water heating in cowsheds and the installation of recuperative and regenerative exchangers in the ventilation systems of livestock buildings [Haš et al. 1985, Adamovský and Kára 2002].

The results of research and full-scale testing in the Czech Republic and elsewhere [Bastron et al. 1999, Kennedy et al. 1991, Lord et al. 1989, Adamovský et al. 2002, Adamovský and Adamovský 2004] gave evidence that systems for heat recovery from circulating air using air-air heat exchangers contribute significantly to energy savings in the heating of livestock buildings, improve the quality of the environment in the buildings, and eliminate the hazard of air humidity condensation on the internal walls of the buildings. It has been found that heat recovery from ventilation air is efficient particularly in livestock buildings with high temperatures and appreciable air circulation.

Whether an energy-saving facility should be installed or not depends on the outcome of a cost-benefit analysis of the project. Among methods which are applicable to such analysis is the basic net profit calculation Method [Riva 1992, Adamovský 1992]. For the purposes of that method the yearly electricity consumption W_e [MJ·year^{-1}] for ventilation of a building can be calculated as

$$W_e = \frac{\sum 3.6 \cdot P_{e,i} \cdot \tau_i}{1000} \quad [\text{MJ·year}^{-1}] \tag{1}$$

and yearly thermal energy consumption for heating of the building W_t [MJ·year^{-1}] as

$$W_t = \frac{\sum 3.6 \cdot Q_{e,i} \cdot \tau_i}{\eta_k \cdot \eta_r \cdot \eta_o} \quad [\text{MJ·year}^{-1}], \tag{2}$$

where

$P_{e,i}$ [W] is the input power of the ventilation fans at outdoor temperature $\theta_{e,i}$
$Q_{e,i}$ [kW] is the required heating power at outdoor temperature $\theta_{e,i}$
τ_i [hr.year^{-1}] is the number of hours during a year during which the outdoor temperature is $\theta_{e,i}$
η_k [-] is the boiler efficiency
η_r [-] is the heating medium distribution efficiency
η_o [-] is the boiler operator efficiency.

The sums in Eqs 1 and 2 are over available values of outdoor temperatures $\theta_{e,i}$ within the interval from the calculation temperature for the given area [ČSN EN 12831:2005] to the long-term maximum temperature average for the given site or the temperature at which the heating power is zero.

Hence, considerations regarding the installation of a costly facility for cooling or heating agricultural buildings should take into account current local climatic conditions. The number of cold days is different not only at various sites but also during different years. The situation at a site can only be considered based on long-term meteorological data.

The number of years during which the temperature at a site is below a specific level was specified by the Czech standard ČSN 73 0542:1977 *Tepelně technické vlastnosti stavebních konstrukcí a budov - Vlastnosti materiálů a konstrukcí* [Thermal technology properties of civil engineering structures and buildings - Properties of materials and structures], which is no more valid. That document divided the Czech Republic into areas based on the calculation temperature, the underlying meteorological data, however, are outdated. The new standard, ČSN EN 12831:2005, also uses old data (1901 – 1950) to describe the climatic conditions in the various areas of the country.

More recent measured and observed meteorological data in the Czech Republic over the period from 1961 to 1990 or 2000 have been published ([KŘIVANCOVÁ and VAVRUŠKA 1997] and [KVĚTOŇ 2001, TOLASZ et al. 2007], respectively). The data, however, are not detailed enough to enable the cost effectiveness of air-conditioning facilities to be assessed.

It is the aim of the present paper, based on current meteorological data to calculate the average number of hours during a year during which the temperature at a given site is below a specific limiting level, in dependence on the average yearly temperature at the area.

MATERIAL AND METHODS

Climatic conditions at specific areas were assessed based on daily meteorological data over the period from 1 January 1991 to 31 December 2000, obtained from the NGO "National Climate Programme for the Czech Republic" (NKP). The maximum, minimum, and average daily temperatures collected from 30 weather stations are available in the electronic format. The maximum and minimum daily air temperature was determined by using extreme thermometers. The average daily temperature θ_{edm} was calculated from data measured in predetermined time points (θ_{e7} at 7 am, θ_{e14} at 2 pm, and θ_{e21} at 9 pm) as

$$\theta_{edm} = \frac{\theta_{e7} + \theta_{e14} + 2 \cdot \theta_{e21}}{4} \quad [°C]. \tag{3}$$

Weather stations performing continuous measurements at fixed sites (as far as possible) were selected. All of them lie within the Czech Republic between 48.8° and 50.8° north latitude at altitudes from 158 m to 1324 m.

The average yearly temperature served as a parameter describing the site for the purpose of comparison and generalization of the climatic conditions in the various areas. This parameter is time variable. A comparison of the long-term average temperature at various altitudes over the 1991 – 2000 period and the 1961 – 1990 period [Květoň 2001] is shown in Fig. 1. The plot demonstrates that the average temperature during the 1991 – 2000 period was nearly 0.6 K higher than during the 1961 – 1990 period, irrespective of the altitude. Although the World Meteorological Organisation considers the 1961 – 1990 period a normal period, the higher average temperature from the 1991 – 2000 period, which is closer to the current level, was chosen as the characteristic parameter of each site.

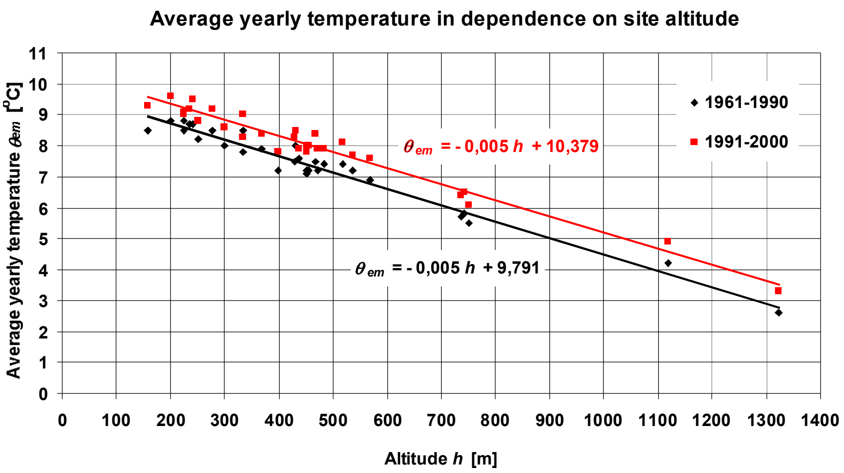

Figure 1. Average yearly temperature at different sites over two different periods of time

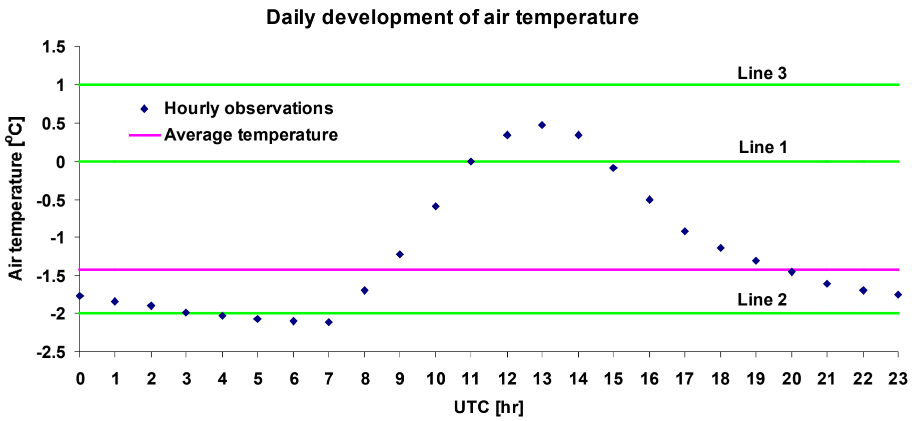

Figure 2. Air temperature development during a typical day in January (1982 – 1998) at the Praha-Ruzyně weather station [KVĚTOŇ 2001]

The weather stations were categorized with respect to the temperature range in which the average yearly temperature falls, viz. 9 °C to 10 °C (6 stations), 8 °C to 9 °C (10stations), 7 °C to 8 °C (9 stations), 6 °C to 7 °C (3 stations), 4 °C to 5 °C (1 station), and 3 °C to 4 °C (1 station).

For each station was calculated the average number of days in a year during which a minimum daily temperature lower than a specific limiting level occurred. The number of such days over the entire decade was identified and the result was divided by 10. The average was calculated for each category of stations, i.e. for each of the above groups of stations with identical average yearly temperature intervals.

Considering a typical temperature development during the day (see Fig. 2), the number of hours during which air temperature is lower than the predetermined limiting level can be estimated.

The graph shows that if the limiting temperature lies between the daily average and the maximum (line 1), instantaneous air temperatures lower than the limiting temperature can be expected for 12 hours (limiting temperature closer to the average) to 24 hours (limiting temperature closer to the maximum). If, on the contrary, the limiting temperature lies between the minimum and average daily temperature (line 2), temperatures lower than the limiting temperature can be expected during the day for 0 hours to 12 hours.

How many times the chosen limiting temperature lies between the average and maximum (or minimum) daily temperatures was ascertained from available meteorological data, and the numbers of days were multiplied by 18 (or 6) hours. Furthermore it was calculated how many times the maximum daily temperature in each area was lower than the limiting level (Fig. 2, line 3) during the entire period of 1991 – 2000. The resulting number of days was multiplied by 24 hours. The sum of the three data is regarded as the number of hours during which the temperature at each site was lower than the limiting temperature. The average values were calculated by the above procedures.

RESULTS AND DISCUSSION

Fig. 3 shows the average number of days in a year over the 1991 – 2000 period during which temperature lower than the chosen limiting level occurred. Low values of temperature occurred either during the whole day or during an unknown number of hours only.

The results are given for 4 areas with different average yearly temperature. The figure enables us to derive the number of days during which heating facilities are run provided than the facilities are activated by outdoor air temperature decrease to below the limiting level.

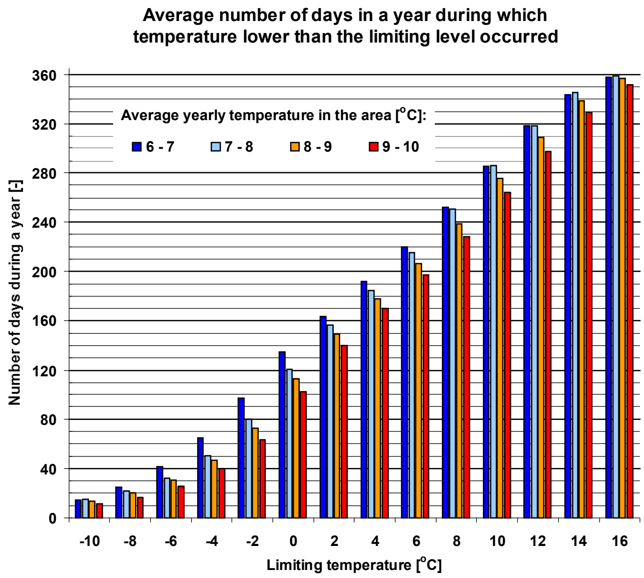

Figure 3. Average number of days in a year within the 1991 – 2000 period during which temperature lower than the limiting level occurred

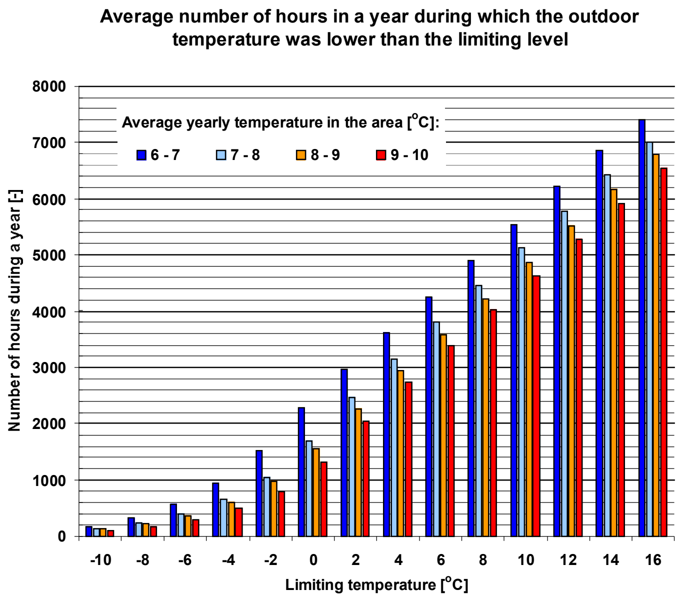

Figure 4. Average number of hours in a year within the 1991 – 2000 period during which the outdoor temperature is lower than the limiting level

The approximate number of yearly hours during which the outdoor temperature is lower than the chosen limiting temperature is shown in Fig. 4.

The differences between the bars with identical colours make it possible, for an area with the specific average yearly temperature to determine the time of occurrence of outdoor temperatures in different ranges (see Table 1). In this manner the τ_i value needed for building ventilation and heating energy calculations from equations 1 and 2 can be derived and a cost-benefit analysis of the installation of a heat recovery exchanger in a livestock building to be made.

Table 1. Average (1991 – 2000) number of hours in a year during which outdoor air temperature lay within the temperature range specified

Temperature range	Average yearly temperature of the area			
	6°C to 7°C	7°C to 8°C	8°C to 9°C	9°C to 10°C
-10°C and under	166	138	133	105
-10°C to -8°C	158	97	86	72
-8°C to -6°C	235	159	149	118
-6°C to -4°C	383	259	233	203
-4°C to -2°C	576	397	368	297
-2°C to 0°C	767	650	586	532
0°C to 2°C	687	762	710	708
2°C to 4°C	649	685	686	709
4°C to 6°C	632	651	623	647
6°C to 8°C	639	648	638	627
8°C to 10°C	637	668	652	612
10°C to 12°C	686	667	650	641
12°C to 14°C	635	644	652	647
14°C to 16°C	548	579	613	625
16°C and over	1363	1757	1979	2218

CONCLUSION

The use of technologies for heat recovery from ventilation air in agriculture has stagnated during the past decade. A renaissance of the installation of ventilation units with the heat recovery function in agriculture in mild climate conditions can be expected in the future particularly in livestock buildings with high indoor temperatures and air circulation (farrowing houses, piglet breeding houses, chicken breeding and feeding houses). As in the kitchen and swimming pool ventilation technology where various modifications of ventilation units with heat recovery exchangers are designed and manufactured, dedicated units will have to be designed for animal farming buildings taken into account airborne dust, air humidity, and various gaseous impurities (such as ammonia) present in the exhaust air.

No cost-benefit balance for installation of such units can be done without a detailed analysis of the local climatic conditions. The method presented in this contribution makes it possible, based on daily meteorological data to calculate the numbers of days and hours in a year during which air temperature at a site with a specific average temperature is lower than a chosen limiting level. The data enable us to assess the energy demands for air heating at the site and to estimate the energy savings that would be achieved by installation of an energy-saving heating facility in a livestock building.

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