

Article

Tracking Differences in Cow Temperature Related to Environmental Factors

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Abstract: The main objective of this work was to investigate the influence of environmental factors, including air temperature (AT), relative humidity (RH) and temperature–humidity index (THI), on the difference between rectal temperature (RT) and eye temperature (ET) of dairy cows. The monitoring of these parameters is important for the further possible introduction of digitalization in animal welfare, especially in dairy cattle. The mean calculated difference between rectal temperature and eye temperature (RT–ET) was 1.5 °C. The average value of AT was 16.4 °C, and the average value of RH was 59.2%. The average value of THI was 60.4. The results of the study showed that, for the temperature difference ET–RT, a low degree of correlation was found both with temperature and with the temperature–humidity index THI ($R = 0.22$; $R = 0.23$). However, the observed temperature difference of the animal (ET–RT) showed a moderate degree of dependence on the relative humidity of air ($R = -0.32$). Although the positive correlation coefficient for AT and THI points to the higher criticality of summer measurements, the negative correlation coefficient for RH supports the use of infrared thermography for determining the temperature of animals even in a moister barn environment.

Keywords: temperature; relative humidity; temperature–humidity index; infrared thermography camera; heat stress



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1. Introduction

The current possibilities of technology, automation and digitalization allow researchers to collect, store and evaluate data online, which can result in information about the welfare of animals in terms of the animal's health or well-being. These data allow us to immediately use devices that can control part of the technology or adjust the unsatisfactory microclimate parameter. Automation of the measurement of physiological and behavioral parameters of farm animals carried out with minimized disturbance can ensure the timely and correct diagnosis of the health status of cows, allow the prevention of the development of infection and more accurate detection of estrus, and leads to a reduction in environmental stress. Accurate data and accumulated knowledge about farm animals, especially in cattle breeding, save working time and contribute to more efficient herd management [1–4]. Among the physiological parameters, body temperature and its fluctuations are key indicators of animal health and well-being.

Body temperature is used to assess the regularity of estrus and ovulation [5,6], pregnancy [7], increased stress reaction [6], parturition [8] and incidence of disease in cows [4,5,9]. The manual measurement of body temperature is expensive and time-consuming. A potential risk of disease transmission is created, and it is also impractical for the cattle and technical staff to measure temperature throughout the daily cycle [7,10–13]. Some authors have investigated

the possibility of the automatic measurement of bolus reticulo-ruminal temperature [5,14], as well as the automatic detection of body temperature through the implantation of a temperature sensor in the vulvar muscles of cows [14–17]. A non-invasive and safe method is infrared thermography, which displays temperature maps of the measured objects. Any object warmer than 0 Kelvin forms a heat emitter in the infrared part of the spectrum, which is not visible to the human eye. However, with the development of technology, measurement systems have been developed and they can visualize data that can be evaluated statistically [18]. They are used not only in industry, but also in agriculture in the field of veterinary medicine. Idris et al. [19] reviewed the use of various non-invasive methods for measuring heat-stress levels in cattle and highlighted the importance of infrared thermographic imaging for the accurate and rapid determination of external body surface temperature.

The measurement of dairy cow body temperature using infrared thermography (IRT) has shown that the eye, vulval temperature and the highest surface temperature (ST) are good points for determining animal core temperature [18,20]. Due to the fact that IRT can be affected by air velocity and exposure to direct sunlight [21], it can be difficult to obtain an accurate body temperature using IRT image analysis in an unprofessional manner [18,20]. In recent years, many measurements have been made using IRT as a tool to obtain thermal responses in a rapid and non-invasive manner [21]. Core body temperature can be used as an indicator of stress due to excessive heat or cold because its variation between animals is relatively small in a given environment. According to McDowell et al. [22], an increase in the value of RT by 1 °C causes a decrease in their productivity in different types of farm animals. IRT has been successfully used to determine the body-surface temperature of various animal species [17,23,24]. The use of IRT in animal production is cheap, fast, efficient and provides important information without the need for physical contact with the animals [25]. IRT allows the detection of even small temperature changes with accuracy [26], and therefore, it has become important in experiments as a safe method of assessment. IRT has been adopted in animal studies for various analyses, such as metabolic responses to heat stress [27] and diagnostics of inflammatory processes [28,29]. Some studies have linked ET measured by IRT with levels of cortisol in cattle and pigs due to altered blood flow caused in this region in response to stressful conditions [29–31]. Montanholi et al. [32] analyzed temperatures measured by IRT in bovine cattle and observed different temperature patterns depending on the available body area. However, ST boundaries that indicate low, medium, or high stress are not well established in the literature. One of the factors that influence changes in body ST is environmental temperature, which affects skin ST and heat exchange between the organism and the environment [21]. According to previous studies [22], RT and respiratory rate were considered the most suitable parameters for monitoring the heat tolerance of animals, because they immediately respond to changes in the thermal environment. An increase in these parameters indicates a malfunction in the mechanisms of heat release to the surrounding environment. According to Dukes [33], the normal RT range for adult cattle is 38.0–39.3 °C. It is well known that AT is related to humidity, as it has a strong influence on heat exchanges in hot or cold environments, which affects the physiological parameters of the animals [34]. Despite the reduction in the price of the infrared thermography camera, non-contact thermometers or classic digital contact thermometers are more affordable, but this is an invasive method of measurement. Infrared thermal cameras, on the one hand, require expert knowledge and require time to process captured images; on the other hand, the high repeatability of IRT eye measurements has already been scientifically confirmed, which indicates the robustness of the method [35,36], making it a useful method in the practical application of the device for various detection examinations. Of course, it is important to correctly determine the methodology of data collection and their subsequent evaluation. The current level of digitization makes it possible to use a large number of recorders where we can store data in any time sequence. IRT has been used in veterinary and animal sciences mainly to detect surface temperature fluctuations correlating to various surface or core temperatures [37,38]. As stated by [39,40], IRT temperatures of the lacrimal caruncle region of the left eye may correlate with core body

temperature. In practice, this makes it possible to replace rectal temperature measurement with non-contact temperature measurement. IRT can be used to measure aspects of stress in animals. Increasing consumer awareness and demand for better living conditions for animals and the demand for humanely produced products may be satisfied thanks to the use of IRT technology [18,37].

The scientific goal of our research was to verify the reliability and accuracy of eye-temperature measurement using thermovision. The aim of our research was to determine the effect of environmental factors, including temperature, relative humidity and temperature–humidity index, on the difference found between the eye temperature measured by IRT and rectal temperature measured by a veterinary contact thermometer in dairy cows. The results of our work contribute to innovation in the field of comparison of the achieved accuracy of measuring RT by an invasive method and the temperature of a dairy cow's eye using IRT. The achieved values should then be compared with the requirements of veterinarians. In the experiment, we monitored not only the influence of the environment on the obtained data, but also the influence of relative air humidity and THI. We suggest collecting these data from all dairy cows according to how the farmer has divided them into groups.

2. Materials and Methods

2.1. Farms and Animals

This study was carried out on a dairy cow farm in the northern part of the Czech Republic. The herds comprised lactating dairy cows of the Holstein breed after the first to sixth calving (cows without milk production were not included). The dairy cows were kept in loose housing with cubicle resting areas and were fed the same total mixed ratio (60% forage/40% concentrate). The dairy cows were fed twice a day. On the farm was located a tandem parlor. Milking was performed twice a day. The removal of feces was carried out twice a day. The yield of milk solids was 10,000 kg per cow per year.

Our measurements were carried out in the Czech Republic, so it was necessary to comply with Czech legislation. From the point of view of Czech legislation, the said measurement did not fulfil the nature of an experiment on animals; therefore, the said measurement was not discussed by the commission.

2.2. Data Collection

This study lasted from October 2021 to February 2023. We performed measurements in periods when extremely critical climatic conditions did not occur (approximately for level $40 < \text{THI} < 72$). The monitored parameters were as follows: the dairy cow's rectal temperature (RT), the dairy cow's eye temperature (ET), the air temperature (AT), the relative humidity (RH), and the temperature–humidity index (THI). Sufficient acclimatization of the animal in the room where tests are performed is important. The adaptation time should be extended in case of a significant temperature difference in the rooms. This knowledge is confirmed by the research of Schaefer et al. [11] in tracking enzootic bronchopneumonia in calves (BRDC—Bovine Respiratory Disease Complex) using thermal imaging. We were aware of the findings reported by Kou et al. [37], that the body temperature of cattle varies regularly depending on the reproductive cycle and disease status. Church et al. [18] points out the need to ensure stable atmospheric conditions when using thermography. As the author further states, even slight fluctuations in temperature ($<0.8\text{ }^{\circ}\text{C}$) on the surface of the animal's body can lead to incorrect diagnosis. When making thermographic images, it is important to immobilize the animal and maintain the correct distance of the thermal imaging camera from the animal, and the distance should not be less than 1.0 to 1.2 m. During our experiment, we tried to apply the knowledge of the cited authors. When making a thermal image of the eye, the time that has passed since the lid is closed (blinking) is important, because by closing the lid, the temperature of the eye harmonizes with the body temperature. Only clinically healthy dairy cows after the first to sixth lactation, which were at its beginning, were selected for the experiment. The dairy cows were in a barn

with free housing on deep litter (straw); after milking, the dairy cows were herded into a selected area outside the housing facility where they were fixed with barriers on the stand. The dairy cows were allowed to acclimatize, and rectal temperature and eye temperature were subsequently measured using thermal imaging. Data of 271 measured dairy cows were included into the study. Only dairy cows that did not show signs of a stress reaction during physical contact were used in the experiment. The temperature of the left eye was measured with the help of an infrared camera; thus, we followed up on the previous experience of experts [41,42]. The distance of the infrared camera from the cattle's eye was approximately 1 m, as recommended by Church et al. [18]. Emissivity as a sensitive parameter, the setting of which affects the result part of the measurements, ranges from 0 to 1. This depends on what surfaces will be measured and how these materials absorb or reflect the emitted radiation. When measuring the body surface of dairy cows, a value from 0.93 to 0.98 was used in previous studies [43–46]. For the measurements in our research, this value was set according to previous experience to $\varepsilon = 0.95$ for all animals.

In the place of the experiment, before the start of individual measurements, a one-time measurement of microclimatic conditions was carried out on each day, namely:

- Air temperature in the measured object [°C];
- Relative humidity [%];
- Air speed [$\text{m}\cdot\text{s}^{-1}$].

Data were selected for the considered file where the speed of the air flow when scanning the cow did not exceed the value $v = 0.2 \text{ m}\cdot\text{s}^{-1}$. To measure RT, we used a Thermoval Kids Flex (Thermoval systems s.r.o., Zlín, the Czech Republic) digital thermometer with a flexible tip and memory to store the last measured values. The thermographs were recorded using an FLIR SC660 (FLIR, Teledyne FLIR LLC, Wilsonville, OR, USA). The resolution of the camera was $640 \times 480 \text{ px}$. The sensor sensitivity was $<0.03 \text{ }^{\circ}\text{C}$.

The maximum temperature of the left eye of dairy cows was evaluated from thermal recordings (Figure 1). Monitoring of microclimatic condition (measurement in the animal zone) was performed using Kestler Instruments 4000 (Nielsen-Kellerman, www.nkhome.com).

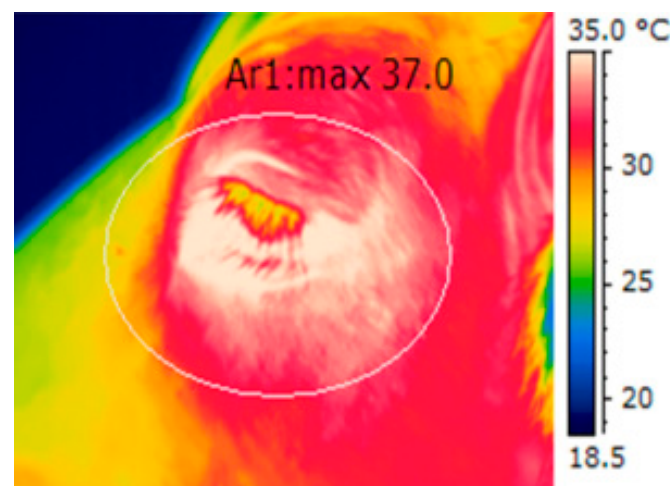


Figure 1. The maximal temperature of a dairy cow's left eye.

The AT and the RH were continuously measured throughout the study to calculate the THI. The AT and RH were recorded by Kestler 4000 meteostation (Kestler Instruments, Shawnee on Delaware, PA, USA).

The THI was calculated based on the values of the AT and the RH. The AT was converted from $^{\circ}\text{C}$ to $^{\circ}\text{F}$. The following formula was used [15]:

$$\text{THI} = \text{Tdb} - \left[0.55 - \left(0.55 \times \frac{\text{RH}}{100} \right) \right] \times (\text{Tdb} - 58) \quad (1)$$

where:

Tdb = air temperature, °F;

RH = relative humidity, %.

2.3. Data Analysis

Evaluated data were from the period from 2021 to 2023. Measurement of eye temperature (ET) using infrared thermography took place simultaneously with the measurement of rectal temperature (RT). Measurements of climatic parameters of air temperature (AT), relative humidity (RH), and air flow (AF) took place in the same object. Temperature–humidity index (THI) values were calculated from the obtained data of ET and RH. From the measured data that we collected during the years 2021 to 2023, we selected data from different seasons so that the data could be classified into individual climatic spectrums. In the statistical evaluation, we focused on the evaluation of the maximum recorded eye temperature and the measured rectal temperature.

2.4. Statistical Analysis

The obtained data were initially processed in Microsoft Office 365 Excel (Microsoft, Redmond, WA, USA). The program Statistica 7 CZ (TIBCO, Palo Alto, CA, USA) was used for the statistical evaluation of the results and for creating the graphs. The data were expressed as means $\pm$ SD (standard deviation). The descriptive statistics, regression method and a one-way ANOVA were utilized. A 95% confidence interval was selected ($p < 0.05$).

3. Results

Although many studies have been devoted to the measurement of the body surface temperature of animals, as well as the measurement of the eye of a dairy cow using infrared thermography, our research team, with long-term measurements, drew attention to the differences that we observed in the same animals by measuring the temperature of the eye by infrared thermography and the rectal temperature by an invasive method in different seasons.

This temperature difference is an important parameter for the precise definition of the justification for the use of infrared thermography. As a substitute method, we measured the temperature of the eye using IRT, representing the temperature of dairy cow's body, so that it was a fully replaceable and repeatable method.

This has not been undertaken so far, and therefore, a targeted comparison of the difference between eye temperature and rectal temperature gives a measurement-verified picture of the declared justification for using this method for further use in automated work procedures in breeding without disturbing the animals with invasive methods of rectal temperature measurement.

Table 1 shows the results of the descriptive statistics of all the data from the farm during the period of study. As can be seen in Table 1, the calculated difference between the average values of eye temperature and rectal temperature was 1.6 °C. The calculated difference between the minimum eye temperature and the rectal temperature was 1.8 °C. The calculated difference between the maximum recorded eye temperature and rectal temperature was 0.1 °C. We carried out our measurements in a period with lower temperatures where there was no threat of heat stress. We tried to avoid days with high temperatures and a THI above 72, as we were aware that a THI above 72 starts to have a stressful effect on high-yielding dairy cows. After measuring the rectal temperature and the temperature of the left eye, the dairy cows were taken back to their group so as not to be unnecessarily stressed. In the statistical evaluation, we focused on the evaluation of the maximum recorded eye temperature and the measured rectal temperature.

Table 1. Results of the descriptive statistics of the farm.

PARAMETER	MEAN	MINIMUM	MAXIMUM	STANDARD DEVIATION
COW'S EYE TEMPERATURE (°C)	36.7	33.9	39.1	0.92
COW'S RECTAL TEMPERATURE (°C)	38.3	32.1	39.0	0.51
AIR TEMPERATURE (°C)	16.4	−1.8	27.4	6.98
RELATIVE HUMIDITY (%)	59.2	38.9	76.8	11.71
THI	60.4	36.7	74.3	9.38

Figure 2 shows the correlation of the air temperature as an external factor in the object of measurement with the values of the difference between the rectal temperature and the eye temperature of dairy cows. The stated values were expressed with a 95% confidence interval. The regression function has the equation: $y = 0.0333x + 0.9585$. It can be concluded that the regression function has a logical interpretation. The AT in the object is positively correlated with the difference between RT and ET. The correlation coefficient with a value of 0.22 ($p < 0.05$) stands for a low degree of correlation. The data show that the higher the AT in the object, the higher the difference between RT and ET.

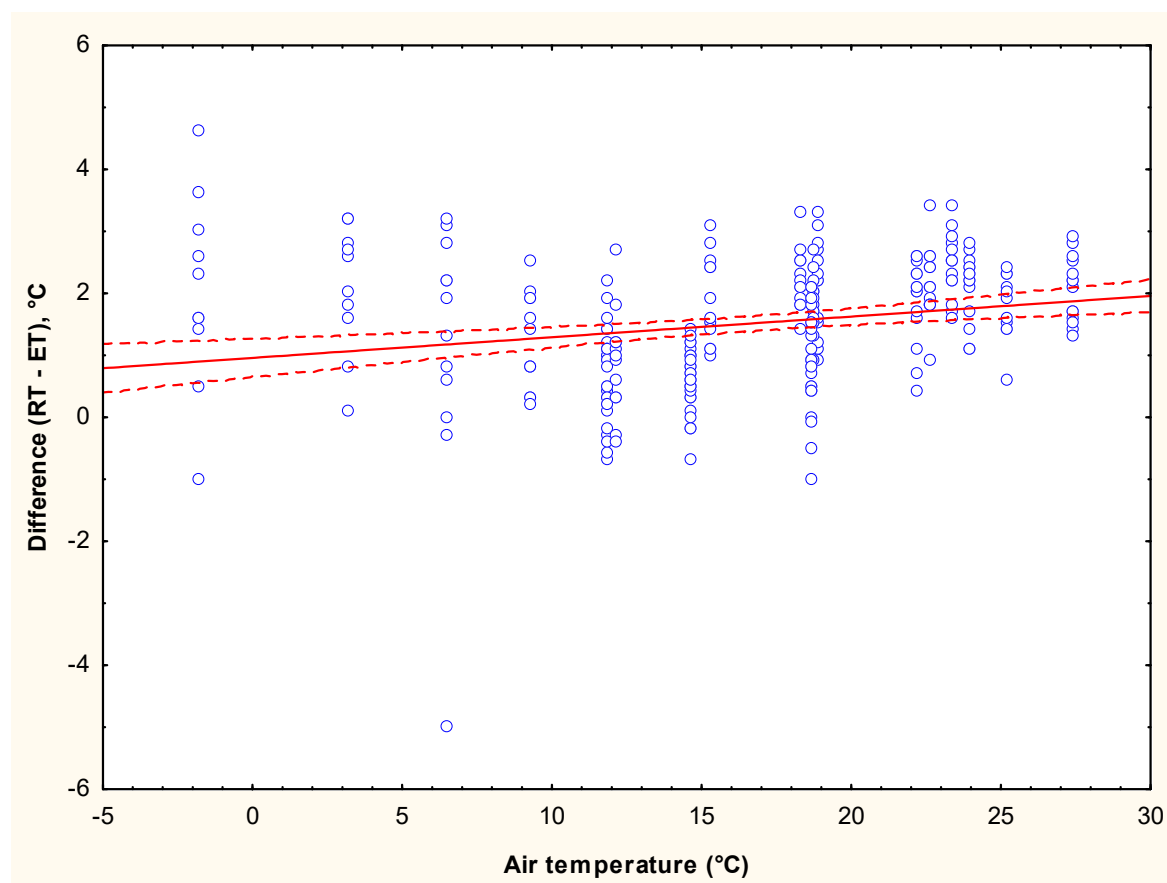


Figure 2. Relationship between the air temperature as an external factor in the object of measurement and the values of the difference between rectal temperature and eye temperature of dairy cows. Dots represent individual recorded values. Red solid line represents linear regression. Dashed lines represent the level of significance 0.05.

Figure 3 shows the dependency between the relative humidity as an external factor in the object of measurement and the values of the difference between rectal temperature and eye temperature of dairy cows. The stated values were expressed with a 95% confidence interval. The regression function has the following equation: $y = -0.0284x + 3.1898$. The

RH in the object is negatively correlated with the difference of RT–ET. The correlation coefficient with a value of -0.32 ($p < 0.05$) stands for a moderate degree of correlation.

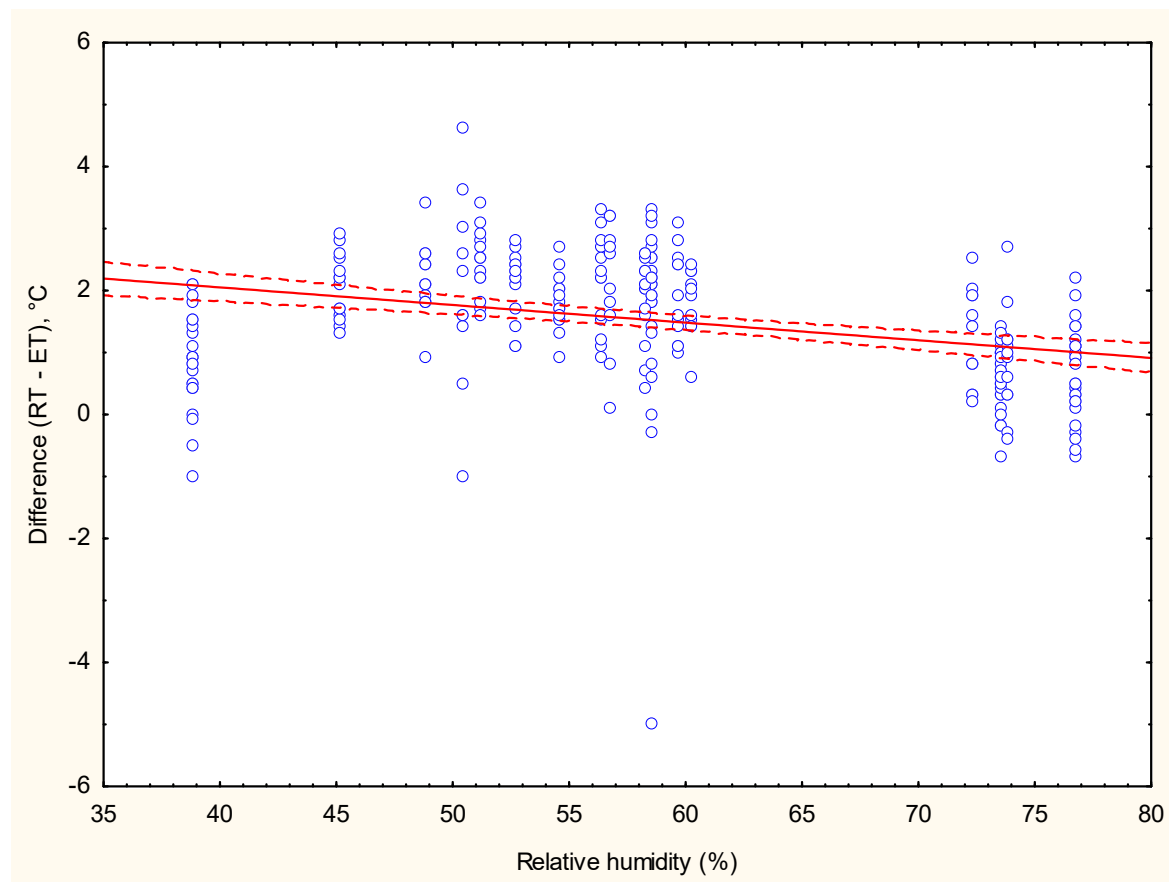


Figure 3. Relationship between the relative humidity and the values of the difference between rectal temperature and eye temperature of dairy cows. Dots represent individual recorded values. Red solid line represents linear regression. Dashed lines represent the level of significance 0.05.

Figure 4 shows the dependency between THI and the measured difference between the values of rectal temperature and eye temperature of dairy cows. The stated values were expressed with a 95% confidence interval. The regression function has the following equation: $y = 0.0258x - 0.0503$. From the above data, we can conclude that the regression function has a logical interpretation. THI in the object is positively correlated with the calculated difference of RT–ET. The correlation coefficient with a value of 0.23 ($p < 0.05$) stands for a low degree of correlation. The above results show that the higher the value of the THI, the greater the value of difference between RT and ET. Identifying critical THI thresholds can help farm staff start up cooling systems in time to maintain cow productivity and ensure animal welfare.

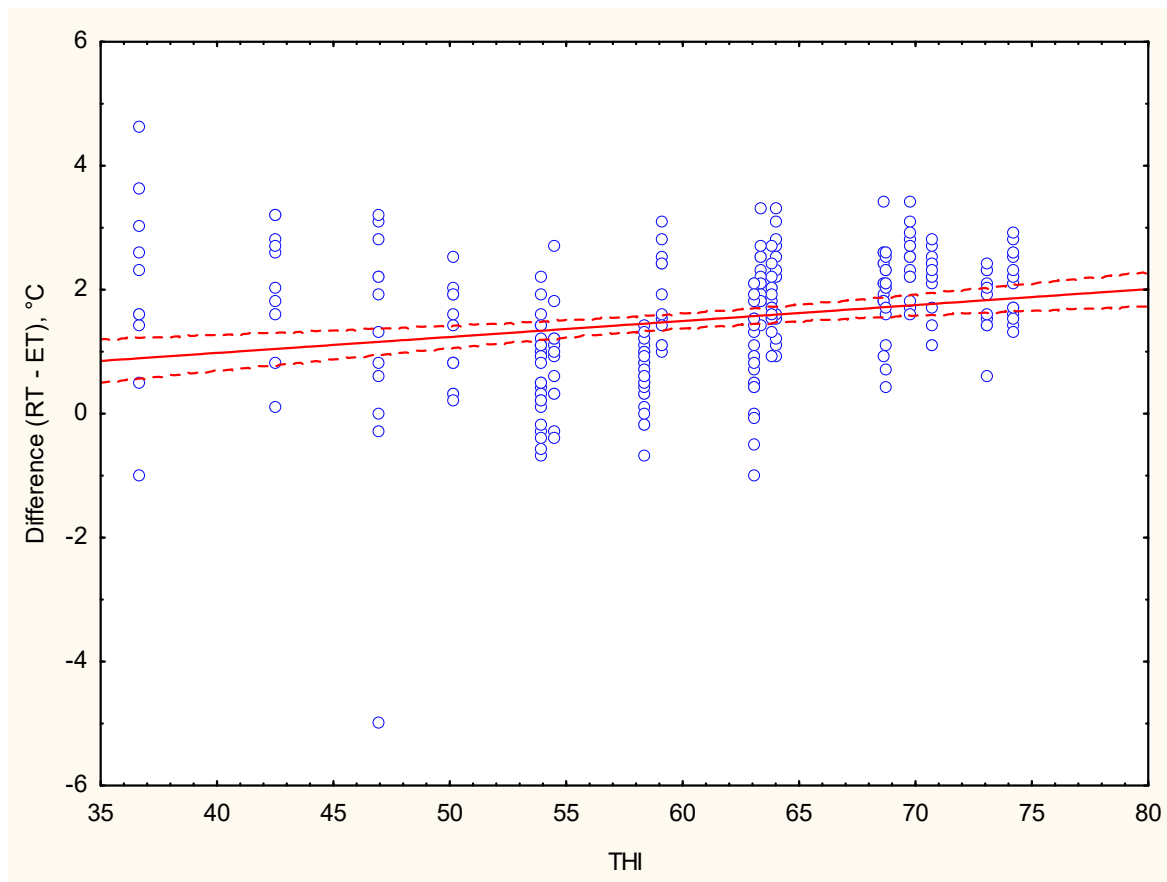


Figure 4. Relationship between the THI and the values of the difference between rectal temperature and eye temperature of dairy cows. Dots represent individual recorded values. Red solid line represents linear regression. Dashed lines represent the level of significance 0.05.

4. Discussion

Our research shows a higher difference between the rectal temperature and the eye temperature than the difference reported by Kou et al. [37]. This could be due to the measurements of the whole eye in our research, while Kou et al. [37] observed only the eye caruncle. The eye caruncle is the most suitable place for measuring the temperature of dairy cows. However, it is very problematic to create high-quality pictures and media in order to evaluate the eye caruncle.

The blood vessels in the milk cow's body expand more, and the ST of the dairy cow's body rises at the same time, as well as the temperature of the lacrimal caruncle of the eye, which is in accordance with the results of the authors Shu et al. [1], who devoted themselves to the evaluation of the most advantageous place for observing the eye temperature of a dairy cow depending on the microclimatic conditions of a housing facility. From the above, it can be understood that it is important to obtain an algorithm for evaluating the influence of THI, the AT in the environment, as well as the influence of RH, which is in line with the knowledge of the authors Jaddoa et al. [42].

Martello et al. [47] recorded lower IRT temperatures measured at the eye (2–7 °C) compared to RT. Other studies involving European breed animals housed in controlled environment facilities reported differences of 3–5 °C between body ST determined by IRT and RT [17]. Montanholi et al. [32] and Berry et al. [48] observed variation (5 °C) in IRT temperatures between different body regions.

As stated by the authors Dado et al. [49]; Kovács et al. [30]; and Oullet et al. [50], an update of THI critical thresholds is based on physiological responses for dairy calves, heifers and cows. As stated by the authors Dado et al. [49]; Oullet et al. [50]; and Pinto et al. [51] (most THI critical

thresholds were based on rectal temperature and respiratory rate. Therefore, we can conclude that it is also important to update and supplement knowledge for a better determination of the influence of THI parameters on RT and ET parameters. Our conclusions are consistent with the work of other authors. Church et al. [18] draw attention to the need to ensure stable atmospheric conditions during thermography, as even a slight fluctuation in temperature ($<0.8\text{ }^{\circ}\text{C}$) on the body surface of an animal can lead to an increase in incorrect diagnoses.

As shown in our measurements, AT and THI are positively correlated, and RH is negatively correlated in the object, to the difference between RT and ET. As stated by Ng and Kaw [39] and Peng et al. [40], it was found that IRT temperatures in the area of the lacrimal caruncle of the left eye can be correlated with body temperature, which essentially serves as a surrogate for body temperature. Here, we want to emphasize that it is important to map how individual parameters affect the environment of RT and ET. Consequently, one can determine whether this method is suitable for monitoring the animal's health or the THI's impact on animals' welfare. However, we must not forget that measuring the RT can cause stress in dairy cows, and thus, those measurements can change the RT as reported by Torrao et al. [52]. The results achieved by Wang et al. [8] are also in similar agreement, which also point to the possibility of using IRT to measure the body temperature of dairy cows. At the same time, they point to the fact that ambient temperature, relative humidity and THI influence the accuracy of non-contact measurement using IRT. We are aware that measuring temperature in a non-invasive way using IRT is an interesting option, but there are several pitfalls that can significantly affect the resulting value. As stated by Mazdeyasna et al. [38] there are many variables in use that significantly affect the measurement results: ambient temperature and humidity, airflow rate, IRT temperature range setting, IRT sensor sensitivity, angle at which images are taken, IRT distance from object, and last but not least, emissivity. Similar to the studies of Burfeind et al. [53] and Naylor et al. [54], from a biological point of view, the depth of penetration of the thermometer into the anus, the presence of feces, and the sporadically problematic handling of the animal probably had an effect on the measurement of rectal temperature. Even with careful handling, this often happens during these actions, which can cause a short-term increase in the body temperature of the monitored animals [37].

5. Conclusions

From the available sources, in which the authors devoted themselves to monitoring the rectal temperature and the eye temperature, they monitored the achieved deviation from the recorded value of the eye temperature using IRT. They statistically evaluated the measured data, which show that IRT can be used as a substitute for measuring the rectal body of animals. However, we subjected our measured data to a different method of statistical evaluation. The calculated difference between RT and ET, which we subjected to a statistical evaluation of evidence, linear regression, we found that the relative humidity is a more suitable parameter for monitoring the dependence, as it is positively correlated with the difference in the mentioned temperatures. The practical goal of our research showed us that the higher the RH, the lower the temperature difference between RT and ET. The results of our study showed that in all three cases, a high degree of dependence of the RT–ET difference obtained by non-contact and contact measurement was not detected in comparison with the environmental factors of the environment. For the RT–ET difference, only a low degree of correlation was found both for temperature (where the correlation coefficient $R = 0.22$) and for the temperature–humidity index THI (where the correlation coefficient $R = 0.23$). However, this monitored animal temperature difference (RT–ET) showed a moderate degree of dependence on relative air humidity. The positive correlation coefficient for T and THI draws attention to the high criticality of summer measurements, when, especially in extremely hot and dry weather, higher temperature differences between the detected methods should be expected. Here, we have to realize that if we are looking at the difference between RT and ET, the time passed since the closing of the eyelid (blinking)

is important because by closing the eyelid, the temperature of the eye harmonizes with the temperature of the body. Since the relative humidity of the air is usually higher in housing facilities for dairy cattle, the use of infrared thermography for detecting the increased temperature of animals appears to be a more accurate method even in a wetter environment (which is an advantage for this type of measurement. This moderate degree of negative correlation dependence, through verified measurements during three years, after further refinement of the methodology supports the validity of thermovision measurements in dairy farming facilities to ensure good welfare for dairy cows.

Author Contributions: Conceptualization, A.L. and I.K.; methodology, A.L. and I.K.; software, A.L. and Š.B.; validation, R.G., Š.B. and I.K.; formal analysis, A.L. and I.K.; investigation, Š.B. and P.K.; resources, P.K.; data curation, Š.B. and P.K.; writing—original draft preparation, A.L. and Š.B.; writing—review and editing, A.L. and I.K.; visualization, A.L., Š.B. and I.K.; supervision, R.G., Š.B. and I.K.; project administration, R.G.; funding acquisition, R.G. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflicts of interest.

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