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DEVELOPMENT AND VERIFICATION OF MICROCLIMATE CONTROL SYSTEM FOR ENHANCED DRIVER COMFORT AND SAFETY BASED ON SKIN RESISTANCE MEASUREMENTS

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This study deals with the design and construction of a device that enhances driver comfort and safety by automatically adjusting the microclimate in the vehicle cabin based on real-time skin resistance measurements. Using electrodes attached to driver's skin and an Arduino microcontroller, the system monitors and evaluates skin conductivity and adjusts heating, ventilation, and air conditioning (HVAC) settings accordingly. Experimental verification in laboratory conditions demonstrated device's functionality in changing microclimate parameters. Preliminary results suggest a potential correlation between baseline skin resistance values and the magnitude of observed changes in response to ambient conditions. Subjects with lower baseline skin resistance ($\leq 100,000 \Omega$) showed smaller changes compared to those with higher baseline resistance ($\geq 100,000 \Omega$). The current results are graphically processed as the course of skin resistance changes depending on the changing parameters of microclimate.

Keywords: HVAC; Arduino; psychogalvanic reflex; autonomous system; thermal environment

The autonomy of vehicles in the automotive and agricultural industries has brought countless benefits over the past decade. These innovations have not only increased road safety but also improved the comfort of vehicle occupants (Mehel et al., 2023). Autonomous systems allow drivers to focus on driving without the need for constant adjustment of various vehicle parameters, which is crucial for preventing distraction and reducing fatigue (He et al., 2024). One important aspect that affects driver well-being during driving is the microclimate in the vehicle cabin (Partin, 2006). Traditional manual adjustment of cooling, ventilation, and heating parameters can be challenging and potentially dangerous if the driver must focus on these tasks while driving (Kousis et al., 2022). In this context, it is important to develop technologies that can automatically monitor and adjust the microclimate without manual intervention. The goal of this study is to design and construct a device that analyses driver's condition through changes in their skin resistance and psychogalvanic reflex (Montagu, 1964). This device uses electrodes attached to driver's skin (Mercier et al., 2022), which are connected to an Arduino microcontroller (Shin and Choi, 2022). It is assumed that the system will be able to monitor skin's electrical resistance and evaluate driver's condition in real-time (Vavrinsky et al., 2012). The device will automatically adjust the HVAC settings (fan, air conditioning, temperature, air flow) to optimise cabin's microclimate (Vashisht and Rakshit, 2021). This research has the potential to significantly enhance driver safety and comfort. Automated microclimate systems can

help keep drivers in an optimal state of alertness and well-being (Buchecker et al., 2022), reducing the risk of accidents caused by fatigue or distraction (Tolis et al., 2021; Yin et al., 2023). The next step in our research is to test the device in real-world conditions and optimise its functionality for a wide range of users and vehicles.

Material and methods

Device design

One of the research goals was the practical application of the device in commonly available automobiles (Arpino et al., 2022). To increase the likelihood of our device being implemented in vehicles, we chose components and a working principle that would be compact, low-cost to manufacture, yet functional (Herceg and Herceg, 2020). During the device design process, we encountered several issues that had to be resolved, such as connecting the device to the driver, analog signal processing, software signal processing, and the power source and the method of powering the device.

Choice of electrodes

To ensure the most efficient current transition between the device and the monitored person's body, the electrodes must be able to provide constant attachment to the skin for an extended period, must be cost-effective and must ensure suitable signal conductivity. In experimental measurements,

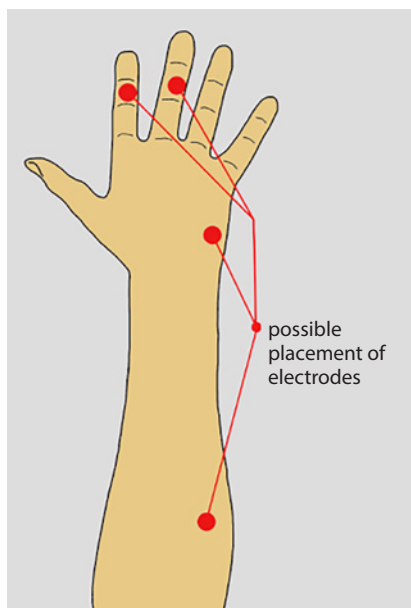


Fig. 1 Placement of electrodes on human hands

disposable ElectroCardioGram (ECG) electrodes were used, which ensure contact between the electrode and the skin with the help of conductive gel. However, this solution is not feasible for everyday vehicle operation. An appropriate solution could be larger contact surfaces made of the same material as disposable electrodes. This issue will be addressed in future research.

The selected electrodes are from the 3M company with the designation "Red Dot electrodes 2228". They are attached to the skin using an adhesive foam ring filled with conductive hydrogel. The contact area is 100 mm².

Electrode placement

The placement of the electrodes on the monitored person is described

in specialised texts, which specify several areas on the human body where they can be placed.

However, the possibilities of placement in a vehicle are quite clearly limited because the skin must be in direct contact with the electrodes and the contact between the skin and the electrode must be as intense as possible for the device to function properly throughout the drive. After filtering out unsuitable areas on the body, the areas shown in Fig. 1 remain. Placing the electrodes on the car steering wheel was evaluated as the only solution, given the amount of time the driver holds the steering wheel and the fact that they hold it with bare skin (Mercier et al., 2022).

Choice of microcontroller

Currently, there is a wide range of microcontrollers on the market that can be used for our research. Among the most widespread and reliable are microcontrollers from Arduino (Xie et al., 2019), we choose the Mega model.

Placement and connectivity of devices

The placement of both devices in the vehicle cabin and their mutual data evaluation connectivity allows sharing a common processor. An alternative is to use three separate microcontrollers with smaller computing capacities (Martin et al., 2021).

Both devices are connected to an individual microcontroller, reducing the data volume compared to the previous variant. Subsequently, their partial calculations are sent to the main microcontroller, which compares the results and determines

the final command for adjusting the microclimate parameters (Beloiev et al., 2021). The schematic wiring used in experimental measurements is shown in Fig. 2.

Powering the device in the vehicle

Our device is designed to be powered through the vehicle's OnBoardDiagnostics (OBD-II) port, ensuring that the system is only powered when the vehicle is in operation. This solution minimises the risk of draining the vehicle's battery when it is not in use. Measurement only takes place when the driver is holding the steering wheel with both hands, as electrodes are placed on the sides of the wheel (Vavrinsky et al., 2012). The combination of powering through the OBD-II port and placing the electrodes on the steering wheel guarantees reliable and precise monitoring of driver's condition during driving without the need for additional installations or modifications to the vehicle (Shin and Choi, 2022).

Creating source code in Arduino Mega

Since the goal is to prepare the open-source solution, we also add the code for Arduino Mega used in this study (Fig. 3). In general, there are a few things that should be noted. The first one is that Arduino Mega has only a 10-bit AD converter; therefore, the value stored in buffer was divided by 1024 (see line 19).

The "if" conditions are used because we want to prepare a device, from which the output will be the binary sequence which can control other devices in the vehicle. Individual output combinations

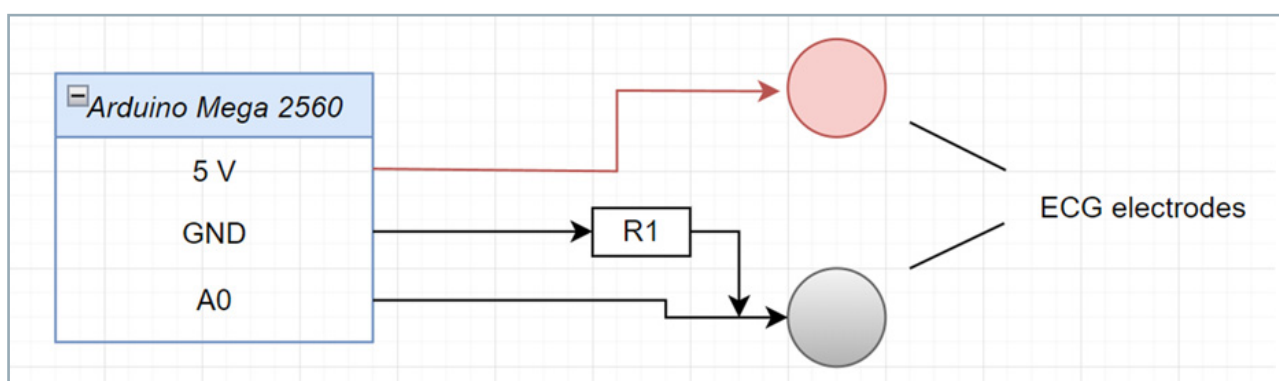


Fig. 2 Block scheme of the device

```

1  int analogPin = A1;    // measure voltage on this pin
2  int raw = 0;           // variable for temporary store values from 0 to 1023
3  int Vin = 5;           // input voltage
4  float Vout = 0;        // calculated value of voltage will be saved in this variable
5  float R1 = 100000;     // resistance of R1
6  float R2 = 0;          // resistance of R2
7  float buffer = 0;      // buffer
8
9  void setup(){           // initialization of ports
10     Serial.begin(9600);
11     pinMode(2, OUTPUT);
12     pinMode(3, OUTPUT);
13 }
14
15 void loop(){
16     raw = analogRead(analogPin);
17     if(raw){
18         buffer = raw * Vin;
19         Vout = (buffer)/1024.0;
20         buffer = (Vin/Vout) - 1;
21         R2 = R1 * buffer;
22
23         if ((R2 > 50000) && (R2 < 100000)){
24             digitalWrite(2,HIGH);
25             digitalWrite(3,LOW);
26         }
27         else if ((R2 > 100000) && (R2 < 150000)){
28             digitalWrite(2,LOW);
29             digitalWrite(3,HIGH);
30         }
31         else if (R2 > 150000){
32             digitalWrite(2,HIGH);
33             digitalWrite(3,HIGH);
34         }
35         else{
36             digitalWrite(2,LOW);
37             digitalWrite(3,LOW);
38         }
39
40         Serial.println(R2);
41         delay(1000); // in ms
42     }
43 }

```

Fig. 3 Code for Arduino Mega used in this study

depend on the “R2” value, using binary code controlling the on/off status and adjusting HVAC actuators, such as cooling, heating, fan speed, and so on. The “if” conditions allow the program to perform certain actions only if specific conditions are met. In this case, the “R2” resistance value is checked. Binary code allows expressing different states or actions using combinations of HIGH and LOW values on various pins (Kristanto and Leephakpreeda, 2018). By adding more “if” conditions and controlling output pins, it is possible to create a flexible program that responds to different resistance values and accordingly adjusts HVAC actuators, thereby adjusting vehicle’s cabin microclimate in response to changes in driver’s skin resistance (Dolinay et al., 2021). In summary, during the loop, the device reads the analog value, calculates the corresponding voltage, determines the sensor resistance, and prints the resistance to the serial monitor every second (Hameed et al., 2019).

Measurement procedure

Before each measurement, the laboratory temperature was between 23.5 °C and 24 °C, with a relative humidity of 44.7%. Each subject was connected to the device via electrodes placed on the palms (Fig. 5) for 10 minutes. The temperature in the laboratory fluctuated smoothly between 23.5 °C and 25.5 °C to record subjects’ response to ambient temperature changes. The subjects sat on a chair. During the measurement, distractions and the movement of their bodies and limbs was minimised.

Results and discussion

To verify the functionality of the device, experimental measurements were conducted under controlled laboratory conditions. The measurement process was recorded

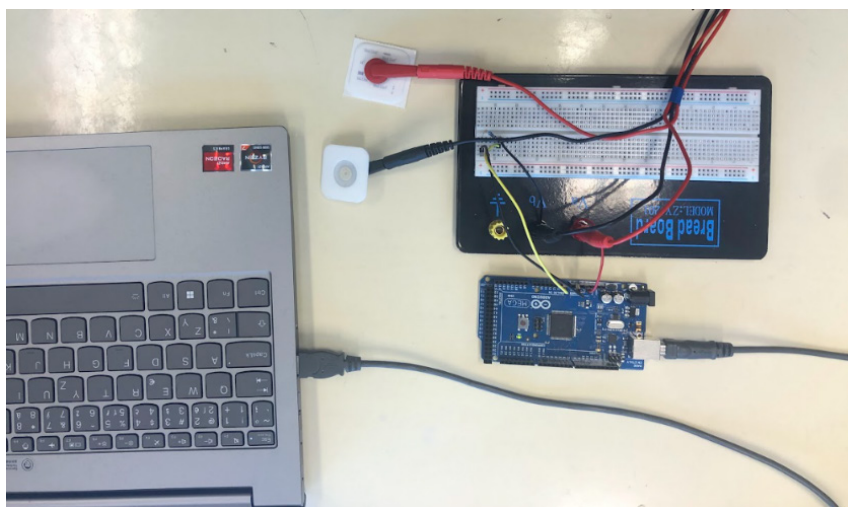


Fig. 4 Actual setup of a device for experimental measurement

and evaluated in real time using a laptop and the Arduino IDE software (Zhang, 2023), with the microcontroller powered by the device, as shown in Fig. 4. The sampling frequency was set to 1 Hz. Device's ability to record subjects' responses to changes in ambient temperature was experimentally verified on a sample of three subjects. The representative sample consisted of: subject no. 1 (a 28-year-old man weighing 95 kg and measuring 186 cm in height); subject no. 2 (a man aged 55–65 years, weighing 75 kg and measuring 175 cm in height); and subject no. 3 (a woman aged 40–50 years, weighing 52 kg and measuring 168 cm in height).

During each measurement, only one subject was connected to the device. The temperature before each measurement ranged from

23.5 °C to 24 °C, while the relative humidity in the laboratory was 44.7%. Throughout the entire 10-minute measurement, the subjects were connected to the device via electrodes placed on their palms (Fig. 5). The subjects sat on a chair. During the measurement, distractions and the movement of their bodies and limbs was minimised. Given the importance of the experiment, the temperature in the laboratory fluctuated between 23.5 °C and 25.5 °C, which enabled us to record subjects' responses to changes in ambient temperature (Hong et al., 2012). The results of the measurements for each subject are shown in Figs 6–8. In evaluating the results for all the three subjects, an inverse relationship between the measured skin resistance and the change in ambient temperature

was observed for each subject. This means that as the temperature increased, a decrease in skin resistance was recorded, and conversely, as the ambient temperature decreased, an increase in skin resistance was observed across the entire sample of subjects (Wang et al., 2020).

By comparing the skin resistance curves between the subjects, we hypothesise that with increasing age or lower body weight, subject's response in terms of changes in skin resistance to temperature increases is less pronounced compared to a younger subject or a subject with higher body weight

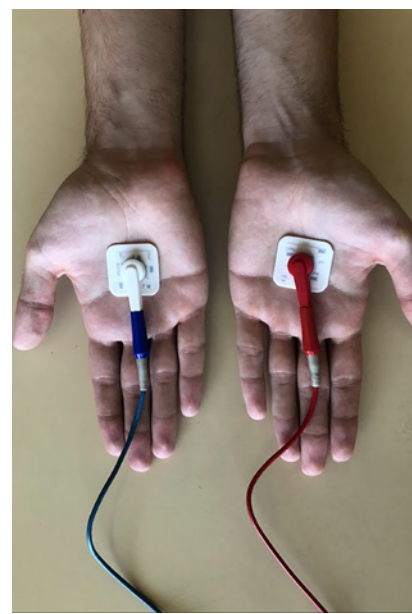


Fig. 5 Placement of electrodes on the measured object

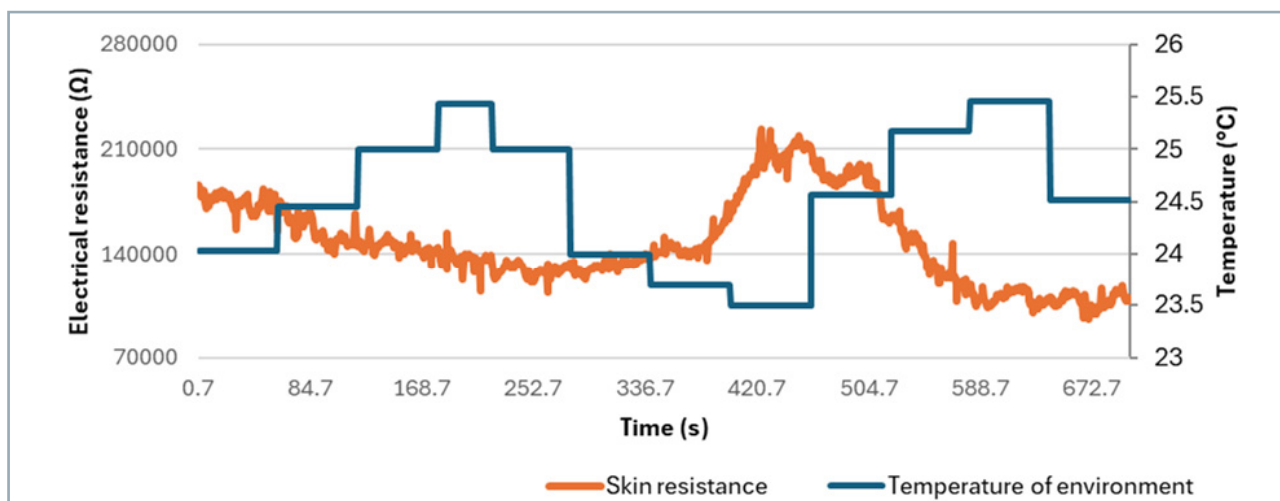


Fig. 6 Skin resistance changes with varying environment temperature (subject no. 1)

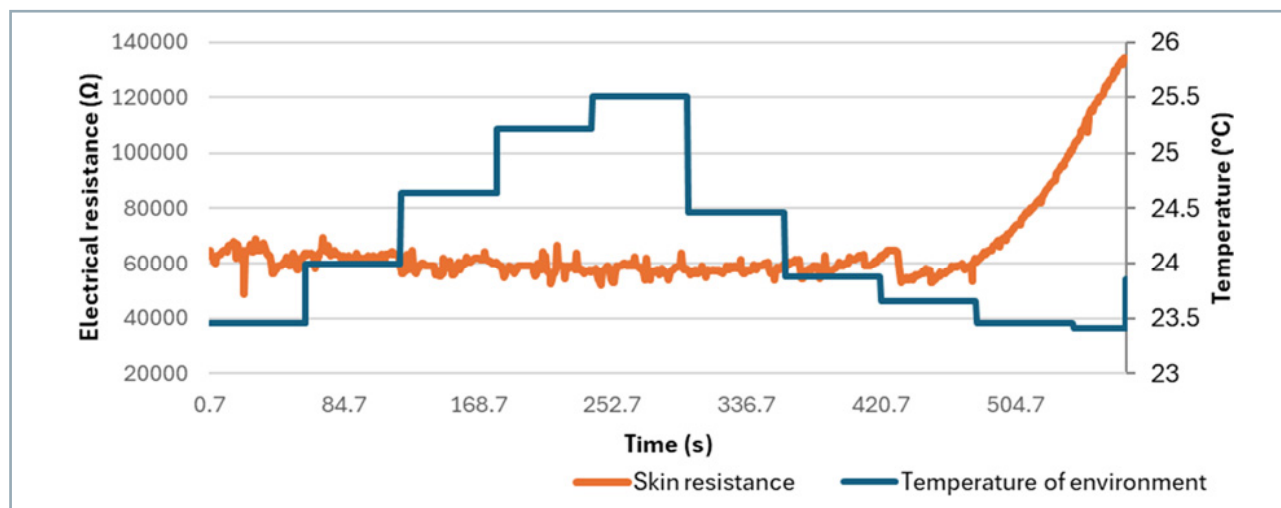


Fig. 7 Skin resistance changes with varying environment temperature (subject no. 2)

(Doberenz et al., 2010). Subject no. 3, a female, exhibited a slow increase in skin resistance with rising ambient temperature, but this change was more pronounced than in subject no. 2 (Pachman et al., 2013).

During the measurement (Fig. 6), the second cycle of ambient temperature increase in the laboratory was achieved due to exceeding the time limit of the experiment. The subject responded to the first temperature rise from 24.03 °C to 25.4 °C with a slight linear decrease in skin resistance from 185,938 Ω to around 130,000 Ω until the temperature started to drop again at 186 s (Hong et al., 2012). A similar pattern was observed during the decrease in the first half of the measurement. In the second half of the measurement, the increase in skin resistance (up to 223,547 Ω) at a lower temperature (23.5 °C) had a steeper growth direction than in the first half due to a 0.5 °C lower temperature compared to the beginning of the measurement. Skin resistance began to decrease almost immediately with the rising temperature from 23.50 °C to 25.46 °C at 460 s, fluctuating down to 103,552 Ω by 595 s. It should be noted that the subject exhibited skin resistance

values above 130,000 Ω even in the preparatory phase of the measurement.

The graphical course of the measurement for subject no. 2 is presented in Fig. 7. Subject's different age and body structure are related to the lower skin resistance recorded (Sim et al., 2019). The subject responded to the temperature increase with minimal to no decrease in skin resistance around 60,000 Ω (Hong et al., 2012); we observed the same pattern during the temperature decrease to 23.40 °C. In the last minute of the measurement, the subject exhibited a sharp increase from 59,972 Ω to 131,932 Ω in skin resistance as the temperature stabilised from 23.5 °C to 23.40 °C. The subject mentioned a preference for higher temperatures and a dislike for cold environments. This statement explains the low change in skin resistance to the rise in ambient temperature and at the minimum temperature where the stabilisation process coincides with the increase in skin resistance (Doberenz et al., 2010).

During the measurement of the third subject, it is important to note the subject's great interest at the beginning of the experiment, which caused both

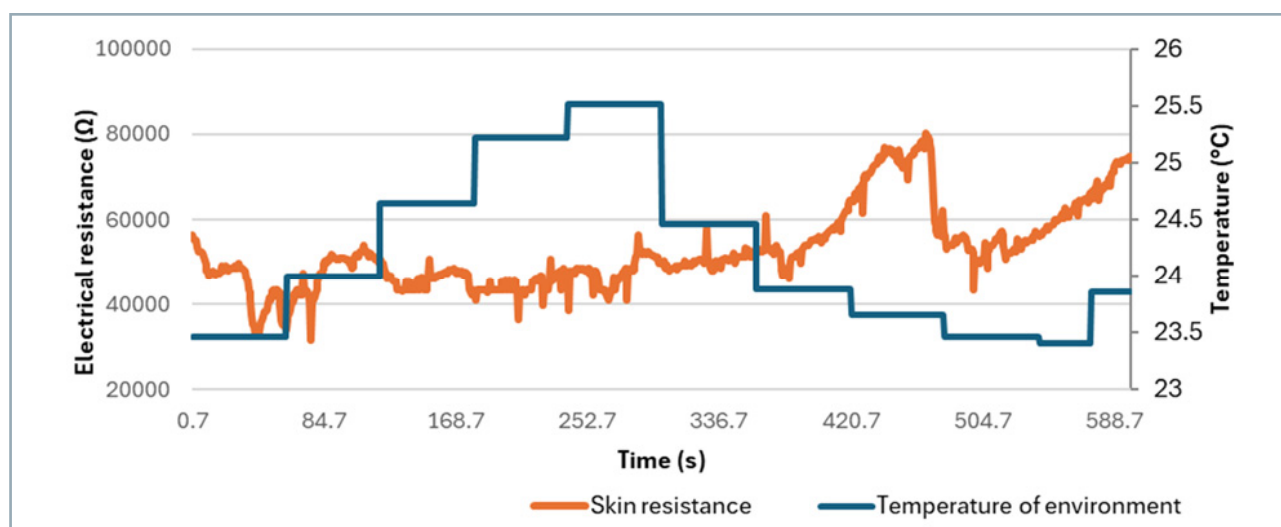


Fig. 8 Skin resistance changes with varying environment temperature (subject no. 3)

verbal and non-verbal communication. In the second half of the measurement, from 302 s, the subject responded to the temperature drop in the laboratory (Pachman et al., 2013), with an exponential increase in skin resistance from 49,220 Ω with temperature 23.88 °C to 79,794 Ω and temperature 23.65 °C at 468 s. The resistance then sharply decreased to 53,154 Ω during the process of temperature stabilisation from 23.46 °C to its minimum 23.41 °C at 504 s.

Conclusion

Based on the experimental measurements, we verified the functionality of our device and the sensitivity of signal recording to changes in microclimate conditions.

From the graphical course of measurements on a sample of three subjects of different ages and genders presented in Fig. 6 to Fig. 8, an inverse relationship between changes in skin resistance and ambient temperature changes is demonstrated. Our measurements clearly confirmed that with increasing temperature, the skin resistance value of a person in such an environment decreases. Conversely, with decreasing ambient temperature, the skin resistance value increases. The growth and decline trends are also significant, depending on the rate at which the temperature changes.

The measurements demonstrated the following skin resistance values for subject no. 1: a change from 185,938 Ω to approximately 130,000 Ω with increasing temperature, and conversely, an increase to 223,547 Ω with decreasing temperature. Subject no. 2 had minimal to no changes in skin resistance with temperature changes, which confirms his statement about temperature preferences. Subject no. 3 had exponential increase in skin resistance from 49,220 Ω to 79,794 Ω with decreasing temperature, and a subsequent drop to 53,154 Ω during temperature stabilisation (Pachman et al., 2013).

Statistical analysis (e.g., *t*-test) confirmed significant differences between the responses of the subjects, with *p*-values <0.05, supporting the hypothesis that age and weight are the factors influencing skin resistance. Preliminary results suggest a possible correlation between the baseline skin resistance value and the ability to observe this change (D'Angelo and Lüth, 2012). If person's baseline skin resistance is low ($\leq 100,000 \Omega$), we hypothesise that the change in skin resistance in response to changes in ambient conditions will be smaller compared to a person with higher skin resistance ($\geq 100,000 \Omega$). Comparing the measurements of subject no. 2 and subject no. 3, we did not observe significant differences in responses to ambient temperature changes, indicating that both genders respond to changes in microclimate parameters in a similar manner.

Our findings are consistent with results from similar studies (Bari et al., 2018), who also report a decrease in skin resistance with increasing temperature. To verify our hypotheses, it is necessary to increase the number of subjects. We will focus on several population groups and their specific characteristics, such as age, body mass index (BMI), and other. Before the measurements, subjects will fill out a questionnaire aimed at their requirements regarding the parameters of environmental microclimate.

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