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Microprocessor device for TEWL coefficient measurement

Abstract. *The paper presents principle of operation and construction of created device for Trans Epidermal Water Loss (TEWL) measurements. This coefficient describes the level of water evaporization through skin. The device measures TEWL in the manner based on the definition of the coefficient. In the article theoretical analysis of the measurement error are presented. In addition there are results of conducted tests in laboratory environment and on real human skin.*

Streszczenie*. Poniższy tekst prezentuje zasadę działania oraz konstrukcję opracowanego przyrządu do pomiaru współczynnika przeznaskórkowej utraty wody. Współczynnik ten opisuje stopień parowania wody przez skórę. Pomiar TEWL jest oparty na definicji współczynnika. Ponadto przedstawiona jest teoretyczna analiza błędu pomiarowego. Na zakończenie zaprezentowano wyniki testów przeprowadzonych w warunkach laboratoryjnych oraz przeprowadzonych na ludzkiej skórze.* ***Przyrząd do pomiaru współczynnika przeznaskórkowej utraty wody***

Keywords: TEWL, measurements, embedded system, tests
Słowa kluczowe: TEWL, pomiary, system wbudowany, testy

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Introduction

One of skin's task is defending the organism from excessive water loss. Layer which does this function is stratum corneum. Healthy human lose ca. 500ml of water during one day. Level of water evaporization informs about skin condition and overall health status.

Coefficient which describes level of water evaporization through skin is TransEpidermal Water Loss (TEWL). It is relation between mass of evaporated water and product of area and time unit. TEWL is defined with these formula:

$$(1) \qquad TEWL = \frac{mass\ of\ evaporized\ water}{area * time} \left[\frac{g}{m^2 h}\right]$$

The coefficient varies depending on place on the human skin. For example, for hand skin it varies from 15 to 40 g/m^{2}h, for forearm from 5 to 25 g/m^{2}h.

The developed device uses ventilated chamber for TEWL measurements. This method is based on the coefficient definition and uses air flow, which gets wetter after skin contact. Difference of inlet and exit air humidity is examined. Because of that it is needed to mount two humidity sensors. Moreover, the mean value of air flow through the chamber in the time unit is necessary.

Before beginning of TEWL measurement, at turned on air flow and measurement head placed on the non evaporating surface the humidity sensors should show the same value (zero calibration procedure). After putting the chamber on the investigated surface air saturates with water. Because of continuous air flow, the inlet sensor shows the same value and exit sensor shows bigger values. After stabilization of readings (some of 30 s) it is possible to calculate TEWL value.

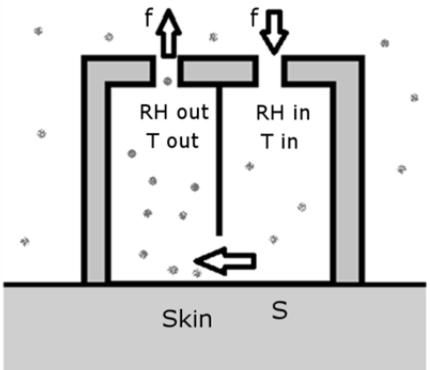

Fig 1 Measurement principle

For TEWL computing it is necessary to use these constants and formulas:

- Constants and measurement results:
  - Relative humidity:

(2) $RH\ [\%]$

  - Temperature:

(3) $T\ [°C]$

  - Air flow:

(4) $f \left[\frac{l}{h}\right]$

  - Water molar mass:

(5) μ = 18,016 $\left[\frac{g}{mol}\right]$

  - Air gas constant:

(6) R = 8,3145 $\left[\frac{J}{mol * K}\right]$

  - Measurement chamber surface in developed device:

(7) S = 0,00031416 $\left[m^2\right]$

  - Vapor pressure in temperature T (PN-EN ISO 13788):

$$(8) \qquad p_{sat} = 610,78 * \exp\left(\frac{T * 17,269}{T + 237,15}\right) \ [Pa]$$

  - Partial pressure of water vapor:

$$(9) \qquad p_{wat} = \frac{RH * p_{sat}}{100\%} \ [Pa]$$

  - Absolute humidity:

$$(10) \qquad \rho = \frac{\mu}{R} * \frac{p_{wat}}{273,15 + T} = 2,165 * \frac{p_{wat}}{273,15 + T} \left[\frac{g}{m^3}\right]$$

  - TEWL:

$$(11) \qquad TEWL = \frac{\Delta m}{t * S} = \frac{m_{out} - m_{in}}{t * S} = \frac{(\rho_{out} - \rho_{in}) f * t}{t * S}$$

Device project

The result of analyzing above formulas and measurement method is ability to define necessary components which are essential for TEWL measurement. It is indispensable to use two humidity and two temperature sensors which measure inlet and exit air parameters. For precise measurement of air flow through measurement chamber it is needed to use adequate air flow sensor. Moreover, a pump for assuring air flow is needful.

Because of clear division of tasks realized by the device (measurement and data processing) it is possible to divide it into two connected parts – desk module and measurement head. Due to that it is possible to move the most of electronics into desk module and reduce size of measurement head. In desk module there is also the pump for creating the air flow. Because of that, in the head there are only humidity and temperature sensors. The air flow sensor is placed in the desk module. Basing on above information it is possible to create list of basic elements and their deployment. In the desk module are placed:

- power supply: MeanWell RS 15-12,
- pump: Schwarzer 250 EC,
- air flow sensor: Sensirion ASF1400,
- control electronics with display and user interface.

In the measurement head there are:

- two temperature and humidity sensors of inlet and exit air: Sensirion SHT25.

Fig 2 Developed device

Computer program

Computer program was developed in C language in LabWindows/CVI environment. Use of that environment significantly accelerate development process. The program consist of one main panel. With that panel it is possible to connect with the device, control it and observe measurement results.

On the panel there are buttons responsible for creating and ending a connection with the device. Next is the button which enables time synchronization. Others are responsible for report control. Moreover there are buttons which duplicate START and STOP buttons placed on the case. Manual control is foreseen also. This mode enables manual control of air flow, switching work mode and measurement and offset correction. Main part of panel is created by 6 charts presenting sensors data and calculated TEWL coefficient. There are also two indicator lights which inform about connection with computer and report generation.

Communication is two-way. It uses interruptions on the either sides – in computer and microcontroller. The device sends the measurement data and receives control messages.

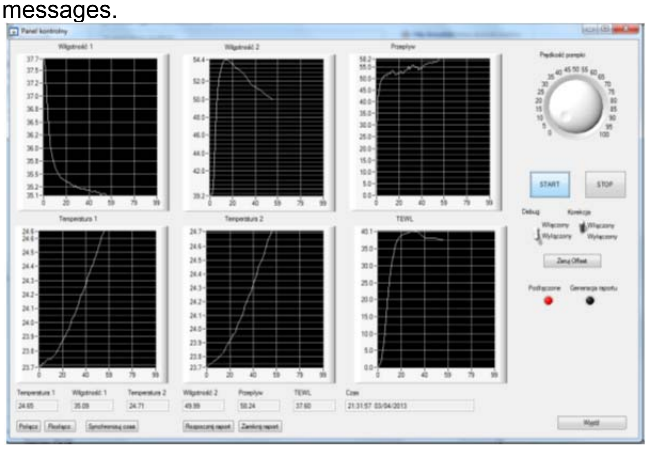

Fig 3 Main panel of computer program

Measurement error analysis

For further analysis these conditions are considered:

- humidity between 20 and 80% RH,
- temperature between 15 and 35°C,
- air flow above 20 cm^3/min.

These ranges can be determined as normal work conditions.

Absolute error is defined by this formula:

$$\Delta TEWL = \frac{\partial TEWL}{\partial f}\Delta f + \frac{\partial TEWL}{\partial S}\Delta S + \frac{\partial TEWL}{\partial RH_{out}}\Delta RH_{out} + \frac{\partial TEWL}{\partial RH_{in}}\Delta RH_{in} + \frac{\partial TEWL}{\partial T_{out}}\Delta T_{out} + \frac{\partial TEWL}{\partial T_{in}}\Delta T_{in}$$

When anti symmetrical sensors are considered the individual components stop compensating each other. If these sensors parameters are defined:

- ΔRH_{out} = 1,8 %RH,
- ΔRH_{in} = 2 %RH,
- ΔT_{in} = 0,4 °C,
- ΔT_{out} = 0,45 °C,
- Δf = 0,01*f cm^3/min,
- ΔS = 0,01 mm^2,

many effects non observable when sensors have got the same parameters show up. An error resulting from determining the temperature gets smaller and difference between humidity has got bigger influence. An error created by air flow is constant.

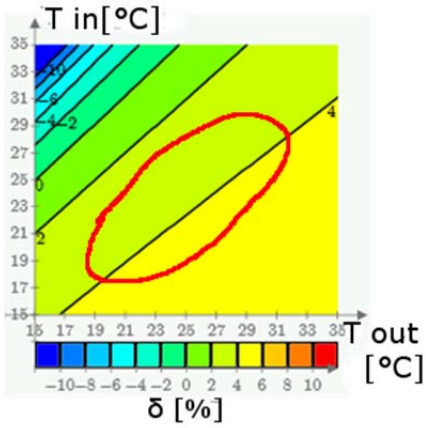

Fig 4 Temperature relative error

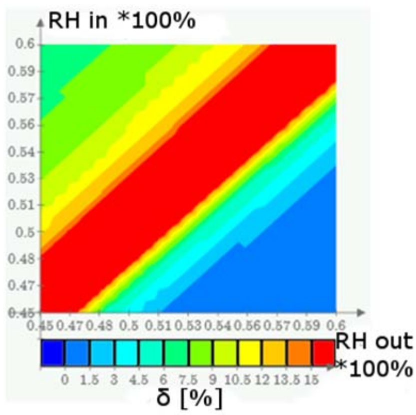

Fig 5 Humidity relative error

Area of sharp growth shows up on the humidity relative error graph. If exit air sensor has got smaller measurement error than inlet, there is a strip of the smallest error which value oscillates around few percent. If situation is opposite, the chart is mirrored along Y=X axe. Moreover, the difference between humidity should be bigger than 5-8% RH. Further analysis lead to the next conclusion – exit gas temperature should be the same or bigger than inlet air. The level of symmetry of the sensors has got high influence on measurement error. It can oscillate from 4 to a dozen of percent. The best option is to use more accurate sensor for exit air measurement.

Table 1 Flow relative measurement error

RH_{in} [%]	RH_{out} [%]	T [°C]	δ flow
20	40	20	2,7%
20	80	20	3,6%
20	40	30	2,6%
20	80	30	3,4%

Calibration

Because of differential measurement of humidity it was essential to calibrate RH sensors. The procedure of calibration was based on closing the measurement chamber and replacing the pump with reference humidity generator. Serial to them dew point hygrometer MICHELL model S8000 was connected.

Three measurement series were conducted for calibration. Temperature and humidity of inlet and exit head air, dew point hygrometer and head temperature readings were measured. Data from sensors and hygrometer were recalculated into water vapour pressure and compared. Difference between readings from Sensirion sensors and dew point hygrometer were base for correction function.

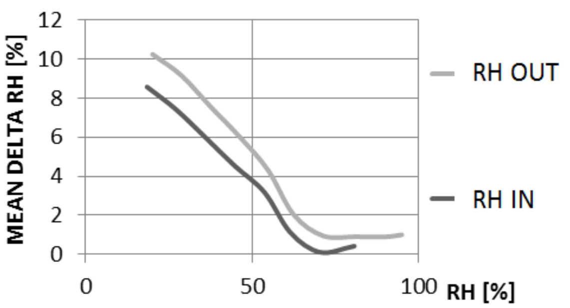

Fig 6 Sensors mean error characteristic

Device tests

The tests were conducted for checking the correctness of readings of the constructed device. The definition of TEWL was used. The water mass difference was measured. The difference was the result of water evaporization, which was controlled by different membranes. The area of membrane was the same as head to connect directly the device's reading and mass loss. After setting the measurement head on the membrane the whole water mass went through the measurement chamber. Thanks to that, observed water loss was exact to device TEWL readings.

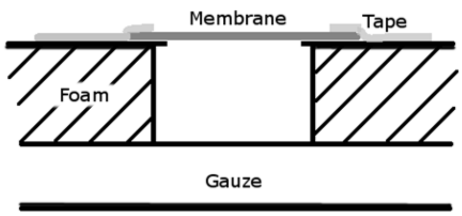

Fig 7 Schematic picture of test bag

The investigated object was zip lock bag with cut out aperture in which the membrane was set. Membrane was glued in the way foreclosing the possibility of evaporating through another way. It was conducted by sticking it by duct tape and creating hole slightly bigger than measurement head area. It was done due to eliminating the error resulting from inaccurate setting the head on the membrane.

Inside the bag was moistened gauze, which was the source of humidity and polyurethane foam with hole. It was used as a spacer.

The weight loss was measured by analytic scale RADWAG XA 60/220. The device has got elementary scale 0,01mg and legalization scale 1mg. For further analysis the scale error was defined as 1mg.

The measurement procedure consist of reading the start mass of the bag (m_{beg}, moment 1 on the picture 8), setting the bag under the measurement head and continous weight monitoring through long enough amount of time. The time was defined by the necessity of performing accurate difference measurement by the scale. Depending on TEWL value the measurement length lasts from one to four hours (samples were gathered with each second). After that time the log was created. Basing on that the average devices' TEWL coefficient was defined (moment 2). The measurement ends with reading the final mass m_{end}.

Due to knowledge of these masses, time and membrane area it was possible to determine TEWL measured by the scale. These two TEWL values were compared.

$$TEWL_{scale} = \frac{(m_{beg} - m_{end})}{\Delta t * S} \quad (12)$$

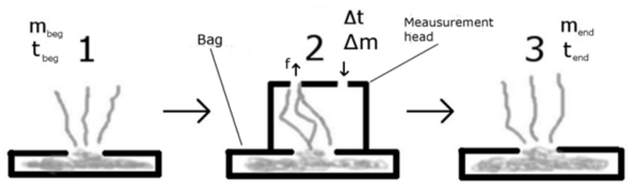

Fig 8 Test idea

Before these tests robustness of the bag and connection between membrane, duct tape and bag was checked by measuring water loss of bag with glued cut out part of another bag playing the role of the membrane. These test assured the robustness of bag and the connection.

After these test proper TEWL tests were conducted. Three types of membranes were used: paper, vapour permeable foil and skin. Additionally these membranes were coated with hand cream.

Table 2 Example tests values for different materials

type	TEWL MIN	TEWL MEAN	TEWL MAX	TEWL DEV	Δ [%]	Time [h:min]
paper	114,6	116,9	119,3	113	3,38	1:21
foil	77,9	80,9	83,9	83,0	2,60	1:03
foil cream	43,1	46,2	49,3	48,8	5,54	1:02
skin cream	14,01	15,05	16,09	13,54	10,0	3:00

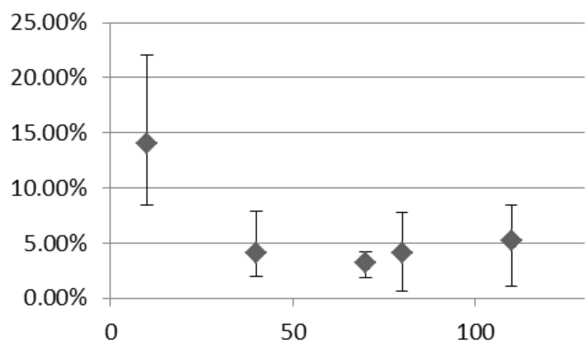

Fig 9 Errors in TEWL function

Analysis of above table lead to conclusion that error grows when TEWL gets smaller. It is the result of not sufficient difference between humidity. Above certain value it stabilizes under 10%. In the most cases the error should be under 9%.

Measurements on the human skin

Multiple measurement on the different parts of the body allows showing measurement stability of the device. Moreover, it is possible to present influence of external conditions and chosen body part. Data was gathered in few series. In each the different body part was investigated. Due to that it was possible to minimize body movements, what have got influence in TEWL.

Following series were conducted:

- Set 1:
  - Internal part of left hand
  - External part of left hand
  - Left arm
- Set 2:
  - Internal part of right hand
  - External part of right hand
  - Right arm
- Set 3:
  - Left ankle
  - Right ankle.

For every body part 15 measurements were conducted.

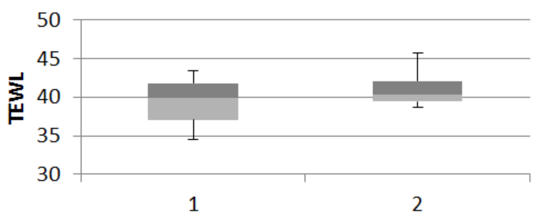

Fig 10 Measured TEWL examples: 1 – Internal part of left hand, 2 – internal part of right arm3

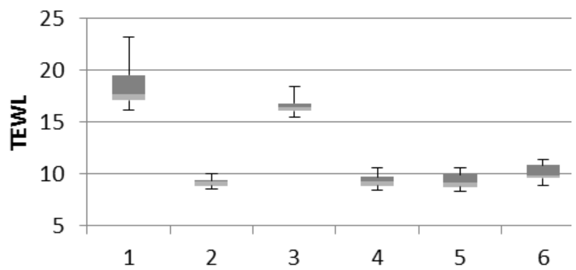

Fig 11 Measured TEWL examples: 1 – left hand top; 2 – left arm; 3 – right hand top; 4 – right arm; 5 – left ankle; 6 – right ankle

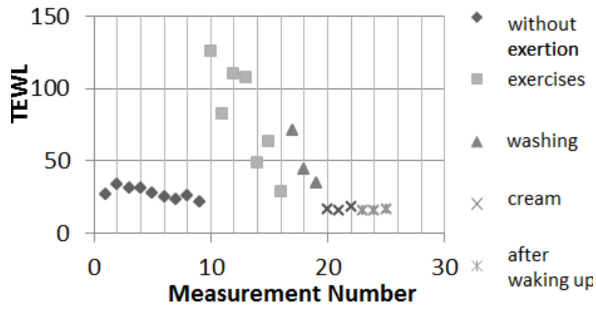

Fig 12 Influence of different factors

Moreover, the measurements showing the influence of external conditions in TEWL coefficient were conducted. They were performed on internal part of left arm. The results present the impact of using the hand cream or physical exercises. The first series was collected during reading of a book, another during and after exercises, the other show the influence of washing hands. The last two were gathered after using the hand cream and directly after waking up.

Conclusion

Result of conducted work is working and practical device for TEWL measurement. It uses widely accessible components. In most cases the developed device has got measurement error under 9%.

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