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USAGE OF MODERN SENSORS FOR THERMAL COMFORT DETERMINATION

VYUŽITÍ MODERNÍCH SENSORŮ PRO URČENÍ TEPELNÉ POHODY

Abstract

The following article deals with human thermal comfort dilemma. Firstly, the sensor for operative temperature evaluation and than synthetic skin type sensor will be introduced. There is no compact sensor on the market, which can measure operative temperature, so the effort is to develop this kind of sensor. It is necessary to measure more physical quantities, like air temperature, mean radiant temperature, air flow velocity and relative air velocity, to calculate operative temperature. Human thermal comfort does not depend only on environment conditions but also on personal factors, which are different for every human being. It's especially energy expenditure and human clothes thermal resistance.

Abstrakt

Článek se zabývá problematikou tepelné pohody. Bude představen snímač pro hodnocení operativní teploty a snímač typu umělá kůže. Na trhu v současné době chybí kompaktní snímač, který by měřil operativní teplotu. Snahou je tedy takový snímač vyvinout. Pro výpočet operativní teploty je nutné měřit více fyzikálních veličin. Jedná se o teplotu vzduchu, střední radiační teplotu, rychlost proudění vzduchu a relativní rychlost vzduchu. Tepelná pohoda člověka nezávisí pouze na podmínkách prostředí, ale také na faktorech osobních, které jsou u každého člověka jiné. Jedná se o energetický výdej a tepelný odpor oděvu člověka.

1 INTRODUCTION

Thermal comfort is feeling, which is being perceived by human in environment. Human is producing heat during different situations and it's necessary to remove this heat produced by human into space, so the body temperature won't be overheated. On the other side, heat dissipation can not be so intensive to prevent strong decrease of human temperature. Human should not feel uncomfortable cold or warm in given environment.

Factors affecting heat transfer between human body and his environment have a big impact on thermal comfort level.

According to fact that energy saving is priority, new solutions where saving energy is the main aim are being found. With growing economy and technical progress, the biggest sources of energy consumption are expenses incurred on human thermal comfort, whether it's in households, work or public transport. However decrease of energy consumption as well as increase of human comfort can be reached using effective regulation of environment temperature state.

It's necessary to effectively monitor environment state and intervene in this state properly and economically. First possibility how to evaluate environment temperature state is use of operative

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temperature sensor, the second option is use of synthetic skin type sensor.

2 THERMAL COMFORT FACTORS

Thermal comfort factors are divided into two groups: factors of environment and personal factors.

Factors of environment:

- **Air temperature** t_a [°C] is interior temperature without influence from surrounding surfaces radiation. The thermometer sensor has to be effectively protected from surrounding surfaces thermal radiation during temperature measurement.
- **Air velocity** w [m.s^{-1}] is physical value determined by own size and direction. In thermal incidence environment is concerned effective air velocity.
- **Mean radiant temperature** $\overline{t_r}$ [°C] is implied uniform temperature from all areas in space during which will be heat transfer from body same as is in reality.
- **Air humidity** at relative humidity between 30 - 70 % is her influence insignificant.

Personal factors:

- **Clothing insulation** - clothes is one of the most important factors affecting heat dissipation from human body to environment. For thermal comfort investigating reasons dimensionless variable was established. Physical unit for this variable is clo. One clo matches insulation compound with thermal resistance R = 0,155 m^{2}K.W$^{-1.}$ One clo is insulation value for casual man coat with cotton underwear. Clo values for some types of clothes are shown in table 1.

Tab 1. Clothes thermal resistance

Clothes	Thermal resistance [clo]
Coat	0,6
Pants	0,35
T-shirt	0,09
Sweater	0,28
Jacket	0,35
Socks	0,02

- **Metabolic heat** – metabolic heat is showing human thermal output. It depends on activity, concrete person (age, stature, physical condition) and conditions in which is concrete person right now.

Tab 2. Thermal flow density produced by human during different situations

Activity	Metabolic rates [W.m^{-2}]
Sleeping	46
Sitting	58
Sitting and working	70
Easy work	93
Quite hard work	116
Hard physical work	180-380

Methods for measuring and evaluating this types of values are written at full length in ČSN ISO 7730 a ČSN ISO 7726.

3 OPERATIVE TEMPERATURE

Operative temperature t_o (°C) is defined as uniform temperature of black closed area, where human body will participate using convection and radiation the same amount of heat as in real thermal heterogeneous environment. Operative temperature is defined by equation:

$$t_o = \overline{t_r} + A(t_a - \overline{t_r}), \qquad (1)$$

where:

t_o - operative temperature [°C]

$\overline{t_r}$ - mean radiant temperature [°C]

t_a - air temperature [°C]

A - coefficient dependent upon flow velocity [-]

Tab 3. Coefficient A on flow velocity w dependence

w [m.s^{-1}]	0,2	0,3	0,4	0,6	0,8	1,0
A [-]	0,5	0,53	0,6	0,65	0,7	0,75

Additional charts and graphs for determination optimal operative temperature are in standards.

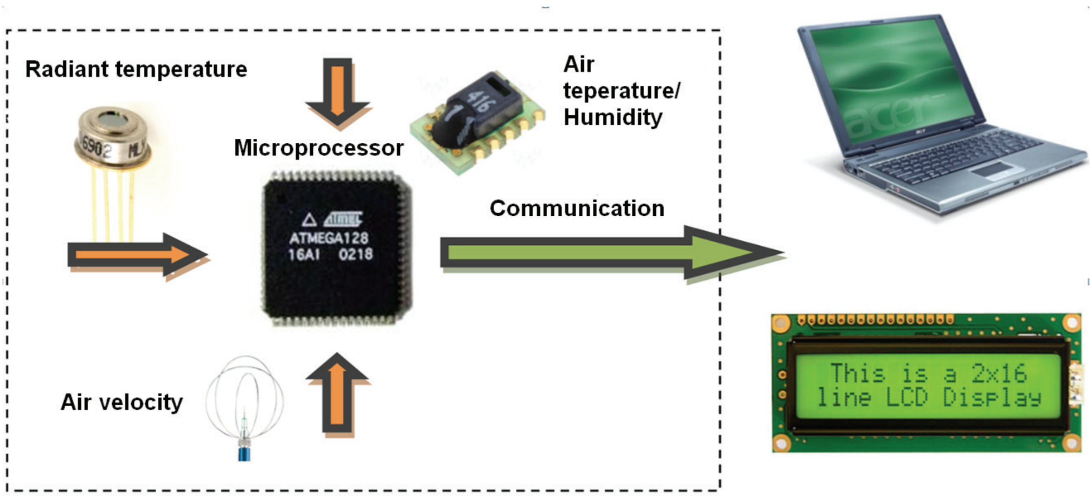

Fig 1. Block diagram of compact operative temperature sensor

Operative temperature as mentioned before is used for evaluating thermal state of environment. There is a lot of different types of sensors and machines, which are able to measure environment factors very accurately as well as calculate the resulting operative temperature. The main disadvantage is quite high price. Our aim is to propose small compact sensor for environmental factors measurement and for determination resulting operative temperature as well. The biggest problem is to find available sensors with accuracy accordant with Standard CSN ISO 7726 and of course price of the proposed sensor may not be too high. Than it will be possible to use this type of sensor for example in buildings for continuous evaluation of thermal comfort in rooms. On fig. 1 is block diagram of compact operative temperature sensor.

4 SYNTHETIC SKIN TYPE SENSORS

These sensors are simulating real human skin with their thermal behaviour and environmental influence. From thermal effect point of view it's radiation of thermal flow into surrounding area. Human is radiating through skin into environment thermal flow 50-200 $W.m^{-2}$ depending on actual physical and psychical state, that's why synthetic skin type sensors have to know how to change value of radiation power. Main part of the sensors is heating unit, than thermal flow has to be evaluated as well as surface temperature. The synthetic skin surface temperature is changing with a change of thermal state of environment. Using this value is possible to evaluate, what will be human feeling in given environment, especially if he feel cold or warm.

Sensor output is one a value - surface temperature, rather equivalent temperature t_{eq} defined by following equation:

$$t_{eq} = t_s - (Q / h_{cal}), \qquad (2)$$

where:

t_{eq} - equivalent temperature [°C]

t_s - surface temperature [°C]

Q - measured convection and radiation thermal loss in real conditions [$W.m^{-2}$]

h_{cal} - compound factor of heat transfer specified during calibration in standard environment [$W.m^{-2}.K^{-1}$]

Construction of these sensors is similar to construction of smart sensor (block diagram of this sensor is shown on fig.2). Heating spiral power which is simulating real human thermal flow is regulated to achieve that thermal flow density will be the same like real skin value with possibility to change this value within the range of 50-250 $W.m^{-2}$ depending on human activity. This help us to evaluate thermal state in different environments with different human mood, if you like environment with different demand on thermal state, for example library (the value close to 100), gym (the value close to 250) etc.

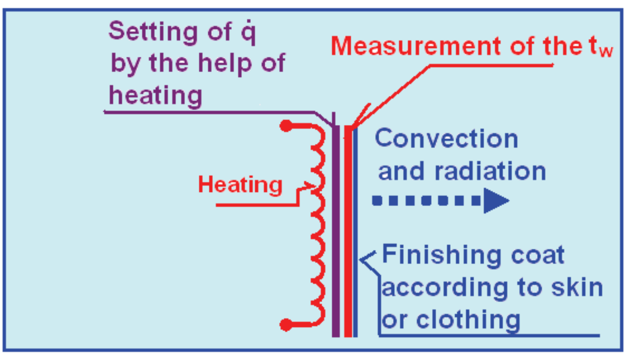

Fig 2. Principle of synthetic skin type sensor

For thermal flow regulation, it is necessary to measure this thermal flow. For this reason, thermal flow sensor HFS-4 is used. For accurate determination of surface temperature is used SRTD-1 sensor. This sensor is sheet resistive sensor PT100 with accuracy ± 0.5%. Heating power is provided by heating element SRFG 102.

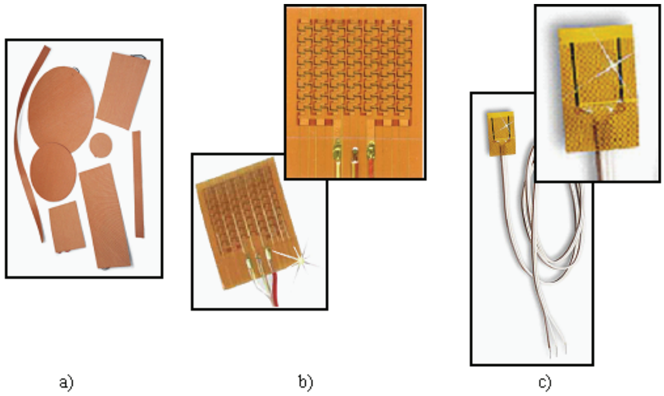

Fig. 3 a) Heating element SRFG 102 b) Thermal flow sensor HFS-4 c) Surface temperature sensor SRTD-1

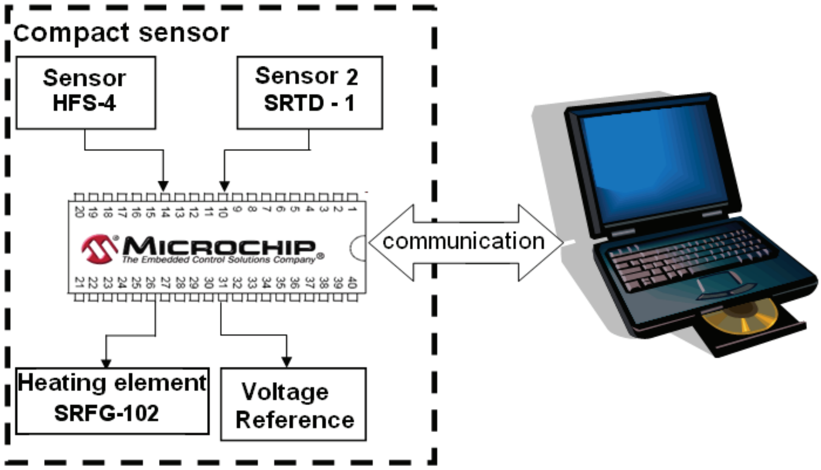

Fig. 4 Block diagram showing sensor and PC

5 USAGE OF SYNTHETIC SKIN TYPE SENSORS

In case of evaluating thermal state of environment as well as impact on human in this environment, the usage of only one synthetic skin type sensor is not adequate and it is necessary to use couple of sensors with placement implying effects on individual human parts. Standard CSN EN ISO 14505-2 is suggesting 32 or 16 areas. For this purpose is used special mannequin, which is complemented with couple of sensors on individual parts of body. Than it is quite easy to evaluate effects on individual areas, which is appropriate solution for vehicle and room air-conditioning proposals.

6 CONCLUSIONS

The article deals with thermal comfort measuring possibilities. The synthetic skin type sensors and operative temperature sensors were introduced. These sensors are being developed at author's workplace and are made especially for this reason. According to right environment evaluation is possible to achieve not only raised human comfort, but with appropriate environment state regulation is possible to get energy saving considering continual evaluation.

This dilemma is part of large project GA 101/09/H050 - The research of energy saving equipment for achievement of interior environment comfort.

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