Project of thermal comfort system

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***Abstract*—** Parameters of interiors are very important for comfort, for energy consumption and cost of utilizing of buildings. There are using some different principles and exists big conservatism. New access in the project of system of thermal comfort is solving it newly. It uses new standards and new view using the knowledge of this category. The project solves measurement system, control system and describes the differences between new and conservative accesses. The measurement system deals about new measurement of meadium radiation temperature and standard measurement of temperature and moisture of air, flow of air in interiors. The control system is projected by new technique a give the opportunity the optimal comfort with minimum of cost for energy.

***Keywords*—** thermal comfort, measurement, control, mean radiation temperature, moisture, flow of air, interior**.**

I. Introduction

Comfort of environment of men in interiors is not simple problem in the work, relax and home environment. Formatting this environment is solid with connection of solving other kind of comfort: light comfort, noise comfort, quality of air comfort and others.

The current conservative solving has a lot of problems and absence of quality parameters of interior for example for hygienic and physiologic conditions for men. Very important is is utilizing measurement and control subsystems for new project solving.

II. Current stage of solving

The first idea to do research the problem by us started up on 1999. The first period of research was during years 2000 up to 2001. There was choice a access according to mathematical models of standards ISO 7730 a ISO 7726. The results of this period are summarized in [1]-[3]. The main argument is that the voted way is right, that there were confirmed technical, scientist and economical efficiencies. But the main problem was, measurement the medium radiant temperature of ambient (SRT).

The next period was till up to 2004. The its activities were applying to measurement of the SRT. The base outputs were presented in [4]-[12]. The thirty period is fallen up to current time. There is project of complex system.

III. Definition of thermal comfort

The strategy of project is built in a model "PMV" . There is defined that thermal energy from body does out according to physical activity, clothing, parameters of ambient: air temperature, air moisture, air flow and surface temperature of interior areas. The problem is showed in fig. 1.

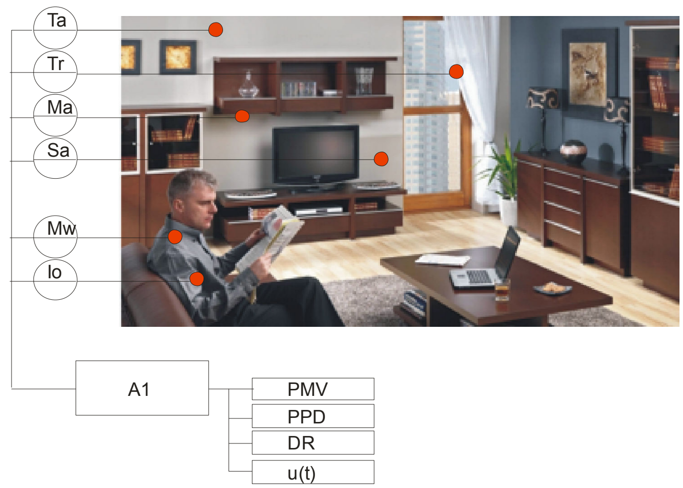

Fig. 1 Scheme of thermal comfort in interior(Ta-air temperature, Tr-radiation temperature, Ma- air moisture, Sa-air flow, Mw-physical activity, Io-clotting, A1-control unit, PMV+PPD+DR-parameter of thermal comfort, u(t)-control value)

The model was defined by [16] and is has the standard [13]-[15]. It has three indexes:

- PMV – predicted mean vote
- PPD – predicted percentage of dissatisfied
- DR – draught rating.

The formula of index PMV according to the model is:

$$PMV = (0{,}303e^{-0{,}036M} + 0{,}028)\{(M-W) + U_1 + U_2 + U_3\} \quad (1)$$

where is

$$U_1 = -0{,}00305[5733 - 6{,}99(M-W) - p_a] - 0{,}42[(M-W) - 58{,}15] \quad (2)$$

$$U_2 = -0{,}000017.M(5867 - p_a) \quad (3)$$

$$U_3 = U_{3a} + U_{3b} \quad (4)$$

$$U_{3a} = -0{,}0014M.(34 - t_a) - f_{cl}.h_c.(t_{cl} - t_a)$$

(5) $$U_{3b} = -0{,}0000000396.f_{cl}.[(t_{cl} + 273{,}15)^4 - (\bar{t}_r + 273{,}15)^4]$$

(6)

$$t_{cl} = t_{cla} + t_{clb} \quad (7)$$

$$t_{cla} = 35{,}7 - 0{,}028(M-W) - I_{cl}.f_{cl}.h_c.(t_{cl} - t_a) \quad (8)$$

$$t_{clb} = -I_{cl}.0{,}0000000396.f_{cl} [(t_{cl} + 273{,}15)^4 - (\bar{t}_r + 273{,}15)^4] \quad (9)$$

$$h_c = 2{,}38(t_{cl} - t_a)^{0,25}\ proh_c > 12{,}1.\sqrt{v_{ar}}\ \text{or} \tag{10}$$

$$h_c = 12{,}1.\sqrt{v_{ar}}\ pro...h_c > 2{,}38(t_{cl} - t_a)^{0,25} \tag{11}$$

$$f_{cl} = 1 + 1{,}290.I_{cl}...pro...I_{cl} \le 0{,}078 m^2 °C/W\ \text{or} \tag{12}$$

$$f_{cl} = 1{,}05 + 0{,}645.I_{cl}...pro...I_{cl} > 0{,}078 m^2 °C/W\ . \tag{13}$$

M energy output from body (W/m2), 1 met= 58,15 W/m^2
W using energy of body (W/m^2)
f_{cl} proportion dressed and undressed part of body
I_{cl} thermal resistance of clotting (m^2.K/W), 1 clo=0,155 (m^2.K/W)
t_a air temperature (°C)
$\overline{t_r}$ medium radiation temperature (°C)
v_{ar} air flow (m/s)
p_a partial pressure of water steam (Pa)
h_c thermal convection (W/m^2.K)
t_{cl} temperature of clotting (°C)
U1,U2,U3 parts of formula of PMV.

Next parameter is the index *PPD*. It is definition, how many people are dissatisfied by concrete thermal comfort. The formula is:

$$PPD = 100 - 95.e^{-U_5} \tag{14}$$

where $U_5 = 0{,}03353.PMV^4 + 0{,}2179.PMV^2$ (15)

The air flow around of body has index *DR* – draught rating. There is very important index, which can say, how much the air flow has influence to thermal comfort. The evaluated formula is :

$$DR = (34 - t_a)(v - 0{,}05)^{0,62}.(0{,}37.v.Tu + 3{,}14) \tag{16}$$

where t_a air temperature
v ait flow (m/s)
$T_u$turbulence (%), rate of standard deviation local flow to average flow.

The special software was developing for testing and learning using. The source text is in table 1.

```
'Program výpoctu tepelné pohody podle ISI 7730/Evaluating software of thermal comfort by ISO 7730
[start]

print "Zadávání vstupních dat/Data entry"
input "Oblečení/Clothing (clo):"; clo
input "Fyzická aktivita/Metabolic rate (met):"; met
input "Vnějsi práce/external work (met):"; wme
input "Teplota vzduchu/Air temperature (°C):"; ta
input "Relativní vlhkost vzduchu/Realative air moisture (%):"; rh
input "Stredni radiacni teplota/mean radiant temperature (°C)"; tr
input "Proudení vzduchu/Air velocity (m/s):"; vel
cls
fnps=exp(16.6536-4030.183/(ta+235))
pa=rh*10*fnps
icl=.155*clo
```

```
m=met*58.15
w=wme*58.15
mw=m-w
if icl<.078 then fcl=1+1.29*icl else fcl=1.05+.645*icl
hcf=12.1*sqr(vel)
taa=ta+273
tra=tr+273
'-----------------povrchová teplota odevu/surface temperature of clothing
tcla=taa+(35.5-ta)/(3.5*(6.45*icl+.1))
p1=icl*fcl
p2=p1*3.96
p3=p1*100
p4=p1*taa
p5=308.7-.028*mw+p2*(tra/100)^4
xn=tcla/100
xf=xn
n=0
eps=.0015
[350]
xf=(xf+xn)/2
'-----------------heat transfer coefficient by natural convection
hcn=2.38*abs(100*xf-taa)^.25
if hcf>hcn then hc=hcf else hc=hcn
xn=(p5+p4*hc-p2*xf^4)/(100+p3*hc)
n=n+1
if n>150 then goto [tisk1]

if abs(xn-xf)>eps then goto [350]
tcl=100*xn-273
'--------------------heat loss
hl1=3.05*.001*(5733-6.99*mw-pa)
'trough skin
if mw>58.15 then hl2=.42*(mw-58.15) else hl2=0
'heat loss by sweating(comfort)
hl3=1.7*0.00001*m*(5867-pa)'respiration heat loss
hl4=.0014*m*(34-ta)'dry respitaion haet loss
hl5=3.96*fcl*(xn^4-(tra/100)^4)'heat loss by radiation
hl6=fcl*hc*(tcl-ta)'heat loss by convection

'-------------calculation PMV, PPD
ts=.303*exp(-.036*m)+0.028 'termal sensation tran coeff
 rozdil=(mw-hl1-hl2-hl3-hl4-hl5-hl6)
pmv=ts*(mw-hl1-hl2-hl3-hl4-hl5-hl6) ' predicted mean vote

ppd=100-95*exp(-.03353*pmv^4-.2179*pmv^2)'predicted percentage dissatisfaction
 turbulence=0.5
 dr= (34-ta)*(vel-0.05)^0.62*(0.37*vel*turbulence+3.14)
 tope=(ta+tr)/2

goto [tisk1]

pmv=999999
ppd=100
```

```
[tisk1]
print "Výsledky výpočtů /Evaluated results:"
print "Oblečení /Clothing(clo)=", clo
print "Aktivita /Metabolic rate (met)=",  met
print "Vnější práce /External work (wme)=",wme
print "Teplota vzduchu /Air Temperature (°C)= ", ta
print "Relativní vlhkost vzduchu (%) = ", rh
print "Střední radiační teplota /Mean radiation temperature (°C) =", tr
print " Proudění vzduchu /Air velocity  (m/s) =",vel
print "Teplota povrchu oděvu /Surface temperature of clothing  (°C) =", tcl
print "Tepelná ztráta povrchem těla /Heat loss through skin (W/m2) =", hl1
print "Tepelná ztráta potem /Heat loss by sweating (W/m2) =",hl2
print "Tepelná ztráta latentní respirací /Heat loss by latent respiration (W/m2) =",hl3
print "Tepelná ztráta suchou respirací /Heat loss by dry respiration (W/m2) =",hl4
print "Tepelná ztráta radiací /Heat loss by radiation (W/m2) =",hl5
print"Tepelná ztráta konvekcí /Heat loss by convection (W/m2) =", hl6
print "Energetický tok z těla /Energy balance of body (W/m2) = ", rozdil
print "Tepelný komfort /Predicted mean vote ()= ",pmv
print "Podíl nespokojených /Predicted percentage dissaticfacted (%) = ",ppd
print "Stupeň obtěžování průvanem /Draught rating (%) =",dr
print "Operativní teplota /Operative temperature (°) =", tope
print " Hodnota turbulence / Valua of turbulence ()=",turbulence

 print " "
 print " "
 print "Další výpočty./Next evaluation ....  ",

goto [start]
```

Table 1 Source text of evaluating software of PMV+PPD+DR

IV. Measuring Subsystem

The subsystem is projected for measuring loops of air temperature, medium radiant temperature, air moisture and air flow. The other two parameters (physical activity as energy output from body and thermal resistance of clotting) constant input.

The measuring loops are using the standard sensor and special arrangement. The sensor of air temperature (position 2 in fig. 2) is a type of NTC thermistor, of air moisture (position 3 in fig. 2) is capacitive sensor, of air flow (position 4 in fig. 2) is NTC thermistor with special arrangement and of radiant temperature (position 5 in fig. 2) is thermopile sensor with special arrangement too.

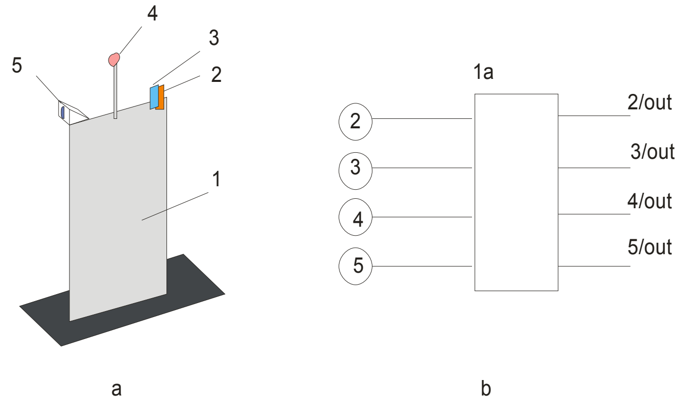

Fig.2 Measuring subsystem (a- devices: 1- body, 2-air temperature sensor, 3-air moisture sensor, 4-air flow sensor, 5-radiant temperature sensor; b-scheme of measuring loops: 1a-electronic unit, */out-output signal of sensors)

The measuring subsystem doesn´t use a measurement with black spherical thermometer (next only BST). There was made a study its parameters and feature.

The temperature in the spheroid was tested by:

- radiation of a half of the spheroid with temperature from 283 to373 K,
- heat transfer coefficient with value of 1, 5, 25 a 100 (W/m^2/K).

Temperature distribution in the surface on the BST is showed in the Fig.3 in the 3D vision. Intern temperature distribution in central area of spheroid is showed in the figures by the head transfer coefficient of 25 (W/m2/K). There is a very difference of temperature asymmetry.

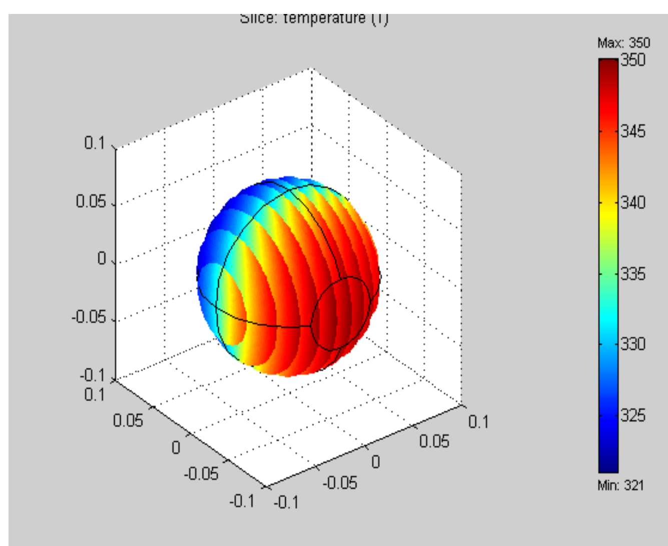

Fig.3 The view on analyzed spherical thermometer in MATLAB-Simulink.

View on the cut in the central area of spheroid, where is tested change of temperature according to change heat transfer coefficient is in the Fig.4.

The dynamic changes of the globe temperature was tested by temperature sensor into the BST. The time temperature change of temperature was determinated for the change for air temperature Ta=293 K, start temperature of radiated body Tr_0=293 K and finish temperature of radiated body Tr_{900}=350 K for time 900 second.

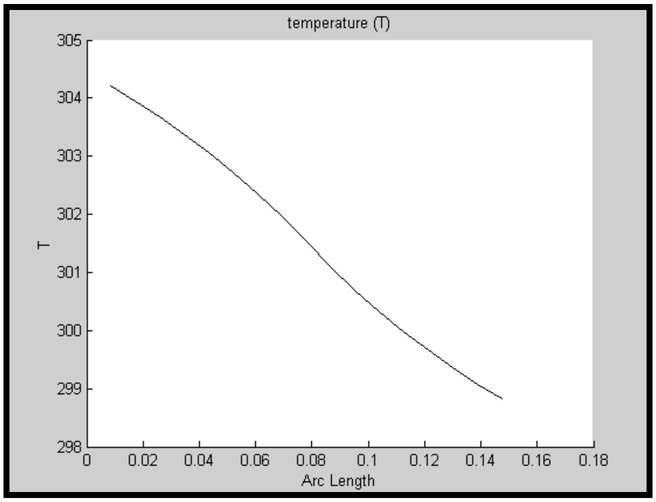

Fig. 4 Distribution of temperature in the cut of spheroid of the BST on the central area

Time characteristics in Fig.5 show course of three points of cut area of spheroid for three points: left, centre and right. The lines tell us that time constant of the first order of system is about 380 second for the point in the centre of spheroid.

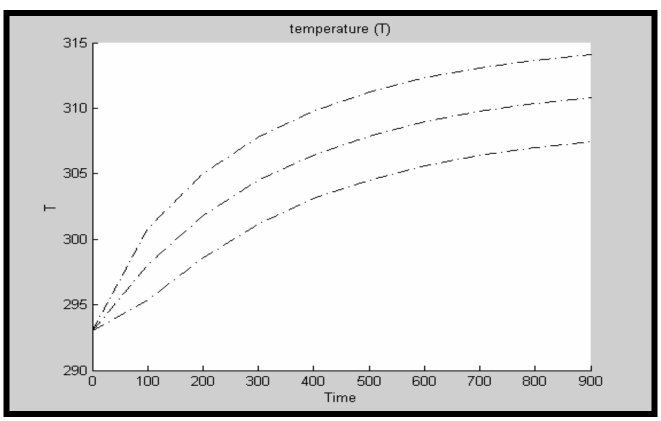

Fig. 5. Time characteristic of temperature the three points of the area

The test of influence the heat transfer coefficient on the globe temperature by measurement with the BST was done in next period of our research. The condition was: static state of parameters, temperature of radiated body Tr=350 K, air temperature Ta=273 K and value of heat transfer constant of 1, 5, 25 and 100 W/m^2/K. That results are in table 2.

h_{cg} (W/m^2/K)	1	5	25	100
Tg (K)	506	336	302	295,5

Table 2 The results of dependence Tg on h_{cg}

The coefficient h_{cg} has eminent influence on globe temperature measured with the BST. Difference gets results by simulation of temperature T_g and the main data is presemted in the table 3.

w (m/s)	Tr=283	Tr=293	Tr=303	Tr=333	Tr=373
1	7	0	-4	-8	-6
5	5	0	-5	-18	-29
25	5	0	-5	-21	-43
100	21	0	-19	-68	-120

Table 3 The difference of temperature Tg and SRT according to changes Tr and h_{cg}.

The all results of the study of BST were presented in (Hruška, 2005,a). The result parameters are not optimal, there is a big time constant and a big responsibility to outdoor trouble situation. The studying was making with help of simulating system MATLAB-Simulink.

Therefore new measuring equipment for medium radiant temperature was developed. There was used the principle of semiconductor thermocouple - thermopile. The thermopile method can measure direct temperature of surface areas in the interiors. There is used the thermopile with a big spherical measuring angle (e.g. 150°rad). The scheme of spherical measurement is in the figure 6.

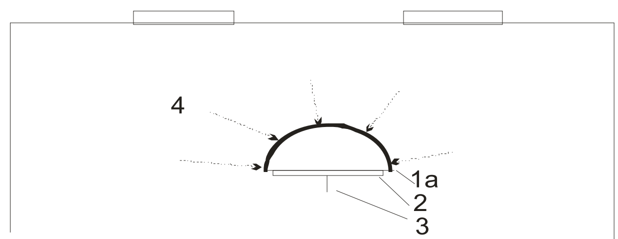

Fig. 6. Scheme of spherical measurement of medium radiation temperature (1a – spherical filter, sensor with electronics, 3- holder, 4- radiation energy)

The concrete device of measurement of medium radiation temperature was chosen and tested the commercial types showed in the fig. 7. There are two types with different angle of measurement and uncertainty.

Fig. 7. Photographs of manufactured types of sensors of medium radiation temperature

The output of measurement MRT is connected direct to central unit and used to evaluation according to PMV model.

V. DESCRIPTION OF MEASURING PRINCIPLE

The medium radiant temperature for assessment of thermal comfort is defined [14] like a temperature that determines the same transmission of radiant warmth from human body in virtual delimited room as in real non-uniform room.

Practically in large manufacturing hall the non-homogeneous fields of thermal radiation influence on human. The standard [14] uses the name "asymmetry" of radiant temperature for this situations.

The devices for measurement of medium radiant temperature have to keep the parameters that are presented in standard. This parameters are for normal medium. For medium with bigger and extreme stress the parameters are in other scale.

The standard [14] brings methods to measuring of radiant temperature. One presents the process of computation of medium radiant temperature according to measured dates of surface temperature of the walls. One else presents: a black spherical thermometer, a double spherical radiometer, a directional radiometer for asymmetry and a radiometer with reflection polished disc or with absorbing black disc. This methods measure radiant temperature indirect and compute it by physical laws. The devices using those methods do not correspondent standard requirements and are not recommended for measurement. For example we verified a device with black spherical thermometer designed according to the standard. The results were:

- the response constant as 500 sec
- the traffic time as 100 sec
- the output signal was influenced by air flow in interior.

The any wall in interior has varied temperature of surface. It radiates the energy on variant intensity. We have taken a premise that sum of actual radiation from several walls is the medium radiant temperature. We can write:

$$\varepsilon_p.S_p.\delta.T_r^4 = \sum \varepsilon_i.S_i\delta.(T_i^4) \qquad (17)$$

We else educe it for medium radiant temperature:

$$T_r^4 = \frac{1}{\varepsilon_p.S_p\delta}.\sum \varepsilon_i.S_i\delta.(T_i^4) \qquad (18)$$

We mean in formulas (17) and (18):
ε_p medium emission factor of interior
S_p all surfaces of walls in interior (m^2)
$Q_{ef,i}$ effective radiation of wall i“ (W), for example:
v-east, j-south, z-west, s-north, str-ceiling, pod-floor
ε_i emission factor of wall „i“
S_i area of wall „i“ (m^2)
δ Stefan Boltzmann constant
T_i absolute surface temperature of wall „i“ (K)
T_r absolute medium radiant temperature (K).

The sensors measuring thermal radiation are offered on adequate assortment. There are this sensors: thermocouple, thermistor, resistive thermometer, bolometer and pyrometer. Pyrometer sensor receives thermal radiation directly and changes it to electric load.

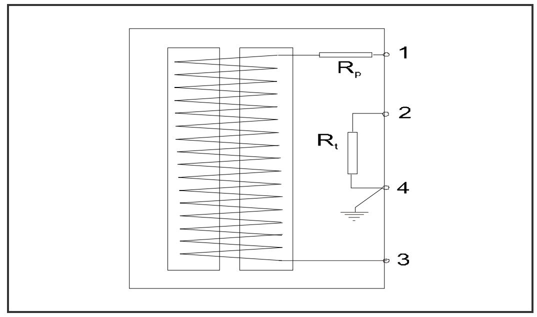

Fig. 8 Intern wiring and connection of thermopile sensor.

We chosen to scan of thermal radiation the sensor created of serial connexion of thermocouples. It pushes up the sensitivity and the output signal of sensor. We chosen the thermopile sensors for testing and learning by different firm for research of measuring of radiation.

The thermopile sensor generaly contains of series more 80 semiconductor thermocouples located at flat around 1.2*1.2 mm enclosed in box of transistor with small window. The box has a window of diathermy material with permeability for concrete wave-length. For standard material there is the permeability higher as 50 % of radiation with wave-length from 5500 to the 14000 nm. Thermopile sensor has a thermistor for measuring of reference temperature inside too. The intern wiring of sensor is in figure 8. The output has to be conected at electronic circuits and to do signal condition and intensity of thermal radiation. The basic parameters of standard thermopile sensors are in table 3

Sensitive area (mm2)	1,2*1,2
Sensitivity (V/W)	20 +/-9
Noise voltage (nV/Hz^{-2})	25
NEP (nV/Hz^{-2})	1,26
Time of stabilisation (ms)	35
R_{25} of thermistor (kOhm)	30
β of thermistor (K)	3964

Table 3 The basic parameters of thermopile sensor

The thermopile module is a measurement system used for the non-contact measurement of surface temperature based on infrared radiation. The thermopile sensor is integrated an ambient temperature compensated module with ellipsoid mirror.

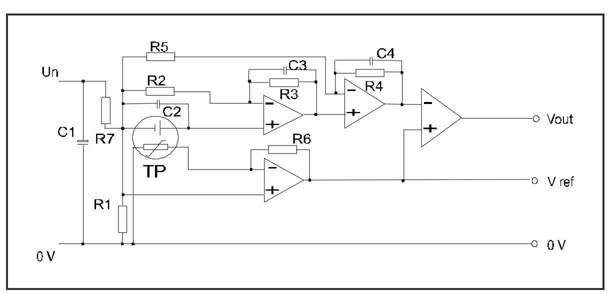

Fig.9 Signal condition circuit of thermopile sensor.

The electronic circuit of module has regularly scheme according to fig. 9. There are a loop for output of thermopile, voltage by small voltage. The other loop is for signal condition of thermistor output. The last amplifier makes summarization the both signals and output is then in range from 0V to (Usuply-2V). The typical response time is up 20 ms.

We meet a problem of determination of angle coefficient of area during the evaluation the indices of thermal comfort by measurement of mean radiation temperature. We can educe it next. We have prepared figure 10, where is showed a radiant situation between a small sensor and a element of area.

We can write:

$$l = \sqrt{x^2 + y^2 + z^2} \qquad (19)$$

and $\cos\gamma = h/l$ (20)

where l distance the sensor and the element
x coordinate of axe X
y coordinate of axe Y
z coordinate of axe Z
γ angle of vector *l* and *h*.

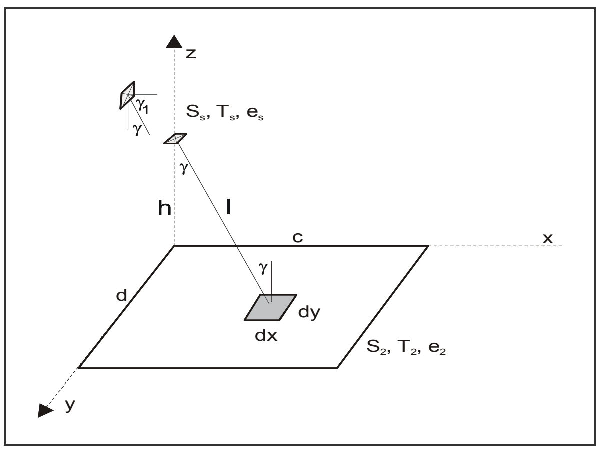

Fig. 11. The relation the radiation between sensor and area.

We can write for the element of area:

$$dA_2 = dx.dy \qquad (21)$$

The elementary angle is showed in formula:

$$d\Omega_{1,2} = dA_2.\cos\gamma / l^2 = \frac{h.dx.dy}{l^3} \qquad (22)$$

The angle trough of the all area (c*d) is a integral:

$$\Omega_{S,2} = \int_{x=0}^{c}\int_{y=0}^{d} \frac{h.dx.dy}{\sqrt{x^2+y^2+z^2}} \qquad (23)$$

We can get after the evaluation next formula:

$$Q_{1,2} = \frac{1}{\pi}\int_{y=0}^{d}\int_{x=0}^{c} \varepsilon_1.\delta.T_1^4.dS_1.h^2..dx.dy/(\sqrt{x^2+y^2+h^2})^4 \qquad (24)$$

$$Q_{1,2} = \frac{1}{\pi}.E_1.dS_1.A \qquad (25)$$

where *A* is the integral of the elementary angle:

$$A = A1 + A2 \qquad (26)$$

$$A_1 = \frac{1}{2}\left[\frac{c}{(c^2+h^2)^{0,5}}.\arcsin\frac{d}{(c^2+d^2+h^2)^{0,5}}\right] \qquad (27)$$

$$A_2 = \frac{1}{2}\left[\frac{d}{(d^2+h^2)^{0,5}}.\arcsin\frac{c}{(c^2+d^2+h^2)^{0,5}}\right] \qquad (28)$$

The formula (23) holds for the angle coefficient between sensor and area (c*d). We can write a formula for a opposite situation. We can write:

$$S^* = S_s.\varphi_{s,2} = S_2.\varphi_{2,s} \qquad (29)$$

where is S* direct exchange area.

The previous relation is valued for the situation, where the sensor and area (c*d) are parallel. We can educe the angle coefficient for the situation, where the sensor and area (c*d) are not parallel. We can use the same way.

The elementary angle is got in formula:

$$d\Omega = \frac{h.dx.dy}{l^3} \qquad (30)$$

The energy flow between sensor and area (c*d) is a integral:

$$Q_{s,2} = \int_{y=0}^{d}\int_{x=0}^{c} \varepsilon_1.\delta.T_1^4.S_1/\pi.h\ .y/(\sqrt{x^2+y^2+h^2})^4.dx.dy \qquad (31)$$

and next

$$Q_{s,2} = \varepsilon_1.\delta.T_1^4.S_1/\pi.B \qquad (32)$$

The constant B is equalled :

$$B = \frac{1}{2}\left[\frac{c}{(c^2+h^2)^{0,5}} - \frac{d}{(d^2+h^2)^{0,5}}.\arcsin\frac{c}{(c^2+d^2+h^2)^{0,5}}\right] \qquad (33)$$

The all formulas presented in previous text are holt for a situation, where the sensor is up the one of the corner of area (c*d). We must divide into more subareas, and sum after evaluation of the partition. The scheme of measurement in area in room is showed in fig. 12.

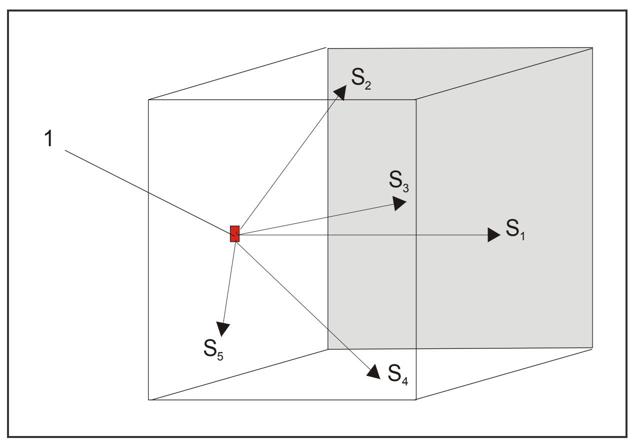

Fig.12. The principles to measurement of medium radiant temperature (1-sensor, S_1, S_2, S_3, S_4, S_5 –areas of half room).

VI. Theory for Calibration

A calibration system was developing to test and to learn the performance of measurement system of mean radiant temperature.

Radiation problems describe the law of electromagnetic radiation. Situation of radiant flux shows figure 3. The body with surface S_2 radiates with energy flux:

$$Q_{2,dop} = \varepsilon_2.S_2.\delta.T_2^4.O/2\pi \qquad (34)$$

where is $Q_{2,dop}$ energy flux from body within spherical angle(Ω)

ε_2 emission coefficient (-)
S_2 radiant surface (m^2)
T_2 temperature of body (K)
δ Stefan Boltzmann constant ($W/m^2/K^4$)
O spherical angle of radiation (sr).

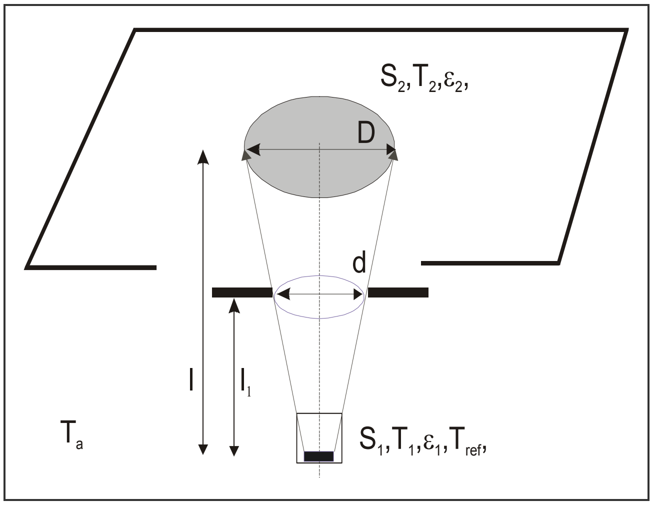

Fig. 13. Geometrical situation of radiant flux.

Geometrical situation of radiant flux is in fig.13. The sensor has surface of S_1 and emission coefficient of ε_1. The one is distanced of l from the area. A covering has distance of l_1 from sensor. It determines the spherical angle.

Energy flux balance between the body and the sensor is:

$$Q_{2,1} = Q_{2,vla} - Q_{1,vla} + Q_{2,odr} - Q_{1,odr} \tag{35}$$

Where is $Q_{2,1}$ flux between body and sensor (W)
$Q_{2,vla}$ flux from body (W)
$Q_{1,vla}$ flux from sensor (W)
$Q_{2,odr}$ reflex flux from body (W)
$Q_{1,odr}$ reflex flux from sensor (W).

The energy flow $Q_{2,1}$ evokes output signal of sensor. It is voltage of semiconductor thermocouple according to heating of sensor with T_1. The output signal is describes on stable state:

$$\Delta U_1 = Q_{2,1}.k_u \tag{36}$$

where ΔU_1 change of output voltage (V)
k_u sensitivity of sensor (V/W).

We can use for calibrating of sensor with simplification this formula:

$$\Delta U_1 = K.(\varepsilon_2.T_2^{4-\psi} - \varepsilon_1.T_1^{4-\psi}) \tag{37}$$

where K proportionality constant
ε_2 emission coefficient (-)
T_2 temperature of body (K)
ε_1 emission coefficient (-)
T_1 temperature of sensor (K)
ψ corrective coefficient (-).

Temperature of sensor area is measured by other sensor of special thermistor.

We have prepared for calibrating the measure device and test system showed in Fig.4.

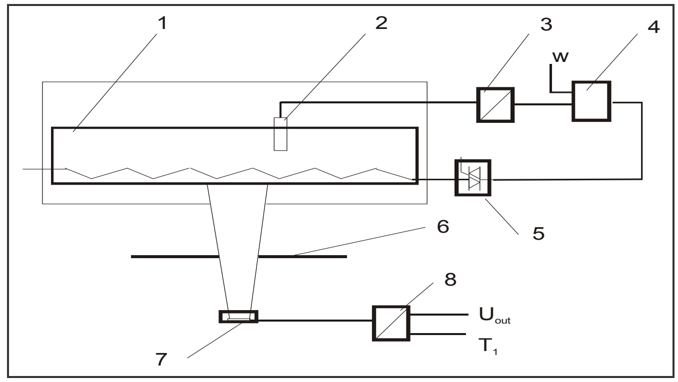

Fig. 14. The schema of calibrating system

The black body (1) in fig 14 is a source of electromagnetic radiation. It is a electrical heated area with outside thermal isolation of warmth transfer in system environment. The surface of body is rugged and black to establish high emission coefficient. Possibility of heating is to 550 °C.

The sensor (2) measures temperature of the body. The thermal conductivity of body material is high, therefore the measured temperature is conforming to temperature of radiant surface. The sensor is a type Pt100, class A. It has a transmitter (3) with range 0 to 550°C.

Controller (4) controls reference value of body temperature. The set value is from 30 to 550 °C. The actor (5) switches electrical power.

Our calibrating system has a black body source (1). It is a simple one. Its emission coefficient is about 0.8. A complex black body is with cavity. We can simulate a temperature range to 1200 °C into this one. The emission coefficient has value about 0,95 here .

The housing of body has a aperture. The sensor is situated in front of the aperture. The spherical angle is adjusted the covering (6). We can change the angle according to distance between sensor and body. The definition of spherical angle is done perfectly.

We perform calibrating process according to formula (34). We measure value of black body temperature T_2 as output of transmitter (3) and inner temperature of sensor T_1 as the second output of circuit (8). The value of emission coefficients ε_2 and ε_1 are known.

We select some testing sequences for concrete reference value of black body temperature. For example T_2 is: 30, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450 and 500 °C. We read voltage output U_{out} and U_{ut} of circuit (8).

We must calculation the measured data for unknown proportionality constant K and corrective coefficient ψ. We use a method of regression analyse for this calculation.

Calibrating gives us information in uncertainly of measurement. We ensure against negative influences during the testing sequences. They are: reflection of radiant and light flux , difference of sensor body and of thermoground of sensor, vertical position of the sensor, form and accuracy of aperture, change of environ temperature.

VII. PROJECT OF EVALUATION UNIT

A next part of project is solving of a evaluation unit. The unit isn´t standard it had to be solved. The project scheme is in fig. 15.

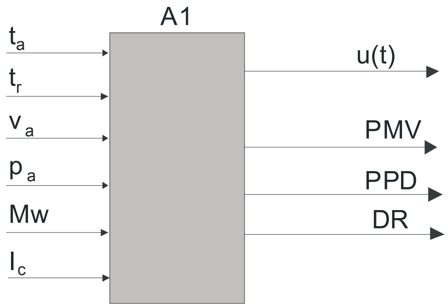

Fig. 15 Block scheme of evaluation unit

The measured parameters of ambient are the first four inputs. The value of Mw (physical activity) and Ic (thermal resistance of clothes) are hand set inputs.

The unit is projected in two versions. The first version is a construction using a embedded microcontroller. There is suitable for battery operation. The other version is unit from field of date acquisition units and notebooks. There was made a theoretical model in Matlab-Simulink and Excel. A reason was to test a simulate the evaluation. The Simulink´s scheme is in fig. 16 and it is in appendix.

The outputs of subsystem are value of PMV, PPD, DR and control signal u(t). The first three output are information, they visualize the parameters of the environment. The output u(t) is continuing signal with signification the control processes.

The scheme of evaluation unit got in the control loop for interior is in fig. 17.

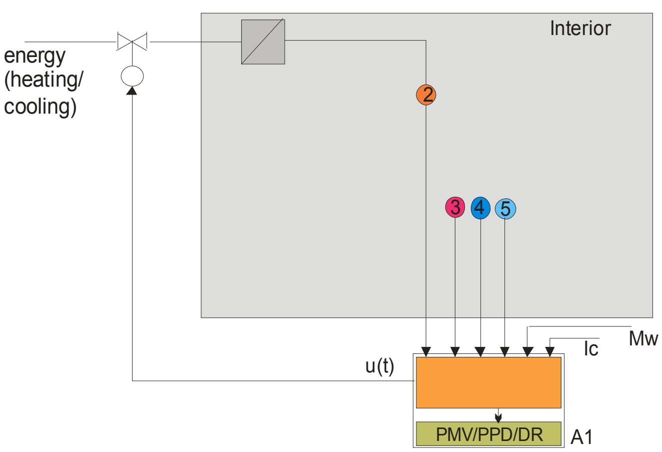

Fig.17 Scheme of control loop with evaluation unit

According to the inputs (2-air temperature, 3-medium radiation temperature, 4-air moisture, 5-air flow and Mw-physical activity, Ic-parameter of cloth) the evaluation unit gives the outputs of information (indexes PMV/PPD/DR) and control signal u(t). The signal controls the inputs energy into interior (in summer cooling energy, in winter heating energy) a change the air temperature in the interior so, that the thermal comfort is PMW=0. In a extreme can be smaller , eg. Ta=<20°C and in other extreme will be Ta>20°C.

The base of construction of evaluation unit is embedded system. The scheme is in fig.18. There is showed: the measuring subsystem with:

- sensors of air temperature T_a, of medium radiant temperature T_r, of air moisture M_a, of flow of air turbulence S_a
- microcontroller system with a multiplex of analog inputs MUX, a programmable gain amplifier PGA, an analog digital converter ADC, a CPU unit MC,
- display unit LCD for vizualisation
- output signal for control u(t) and an interface of data communication USB/RS485/Ethe.

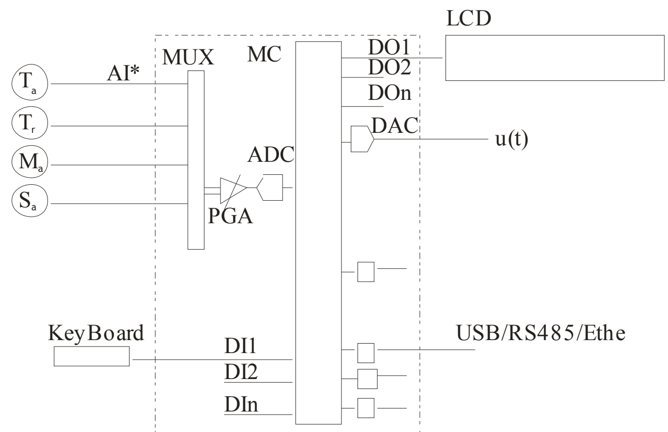

Fig.18 Scheme of embedded system of thermal comfort

The application software of embedded system is developed according to all condition of evaluation of thermal comfort, of control and visualization of its parameters PMV, PPD, DR and of data communication.

VIII. CONCLUSION

The project follows the results reached from research work until 2009. There is used the solving of new measuring equipment, the block measurement for four parameters of interior. There is projected the evaluation unit with information and control functions too.

The results of research confirm the right solving and guaranteed the success of projects. According to the projecting there is a possibility to offer the modern solving of thermal comfort in the interiors by standard ISO .

REFERENCES

[1] HRUŠKA, F. Automatizace techniky prostředí podle tepelné pohody člověka/Automation of environ technique according to termal comfort of men . Doktorská disertační práce/Doctor thesis. Zlín: Tomas Bata University 2001, 97 pp.

[2] HRUŠKA,F. Measurement od medium radiant temperature. In: Proceedings of the 12th Internatinal DAAAM Symposium, pp. 191-192. ISBN 3-901509-19-4. Jena: DAAAM International, Vienna, Austria 2001. MSM 281100001: GAČR 101/01/0345

[3] HRUŠKA,F. Sledování a řízení parametrů tepelné pohody/ Visualization and control of parameters of thermal comfort. AUTOMA, 2001, č.4, s. 61-63. Praha: FCC Public, 2001. ISSN 1210-9592.

[4] HRUŠKA,F. Device for Evaluation of the Thermal Comfort. In: Proceedings of the 3rd INTERNATIONAL CARPATHIAN CONTROL CONFERENCE, s. 57-62. ISBN 80-248-0089-6. Malenovice, Czech Republic, 27-30.5.2002. Ostrava: Technical University in Ostrava.
[5] HRUŠKA,F. Calibration of Measuring device for medium Radiant Temperature. In: Proceedings of the 13th International DAAAM Symposium, pp. 217-218. ISBN 3-901509-29-1. Vienna, Austria: DAAAM International Vienna, 23.-26.10.2002.
[6] HRUŠKA,F. Optimalizace parametrů prostředí podle indexů tepelné pohody člověka (Optimisation of environment parameters according to indices of thermal comfort). ACTA MECHANICA SLOVACA, roč. 6. 2002, č. 2, s. 195-202. ISSN 1335-2393.
[7] HRUŠKA,F. Měření střední radiační teploty /Measuring of medium radiant temperature. Jemná mechanika a optika, roč. 47, 2002, č. 4, s.102-106. Praha: Fyzikální ústav Akademie věd České republiky, 2002. ISSN 0447-6441.
[8] HRUŠKA, F. Measuring Equipment for Control of Thermal Comfort Parameters. In: Proceedings of the 7th International Research/Expert Conference “Trends in the development of Machinery and Associated Technology – TMT 2003, pp. 897-900. ISBN 9958-617-18-8, Lloret de Mar, Barcelona, Spain: Universitat Politecnica de Catalunya, September 2003.
[9] HRUŠKA,F. Bezdotykové měření střední radiační teploty. AUTOMA, 2003, č.1, s. 36-39. Praha: FCC Public, 2003. ISSN 1210-9592.
[10] HRUŠKA,F. Regulace parametrů prostředí podle indexů tepelné pohody člověka. VVI Vytápění, větrání, instalace, 2003, č.1, s. 46-49. Praha: Společnost pro techniku prostředí, 1997. ISSN 1210-1389.
[11] HRUŠKA,F. Uncertainty of measurement of globe thermometer. In: Proceedings of the 15th International Conference on Process Control, pp. 166. ISBN 80-227-2235-9. Štrbské Pleso, High Tatras, Slovak Republic, 7-10.6.2005.
[12] HRUŠKA,F. Měření střední radiační teploty pro stanovení indexů tepelné pohody/Measurement of mean radiation temperature to evaluation of indices of thermal comfort.. Teze habilitační práce / Thesis of habilitation work. Tomas Bata University in Zlin, 2005, 125 pp.
[13] EN ISO 28996:1993 Ergonomics – Determination of metabolic heat production. CEN, Bruxeles, Belgium.
[14] EN ISO 7730:1995. Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. CEN, Bruxeles, Belgium.
[15] EN ISO 7726:1993 Thermal environment. Devices and methods od measurement physicsunits. CEN, Bruxeles, Belgium.
[16] Fanger, P.,O. Thermal Comfort. New York: Mc-Graw-Hill Book Company, 1970. 224 p

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APPENDIX

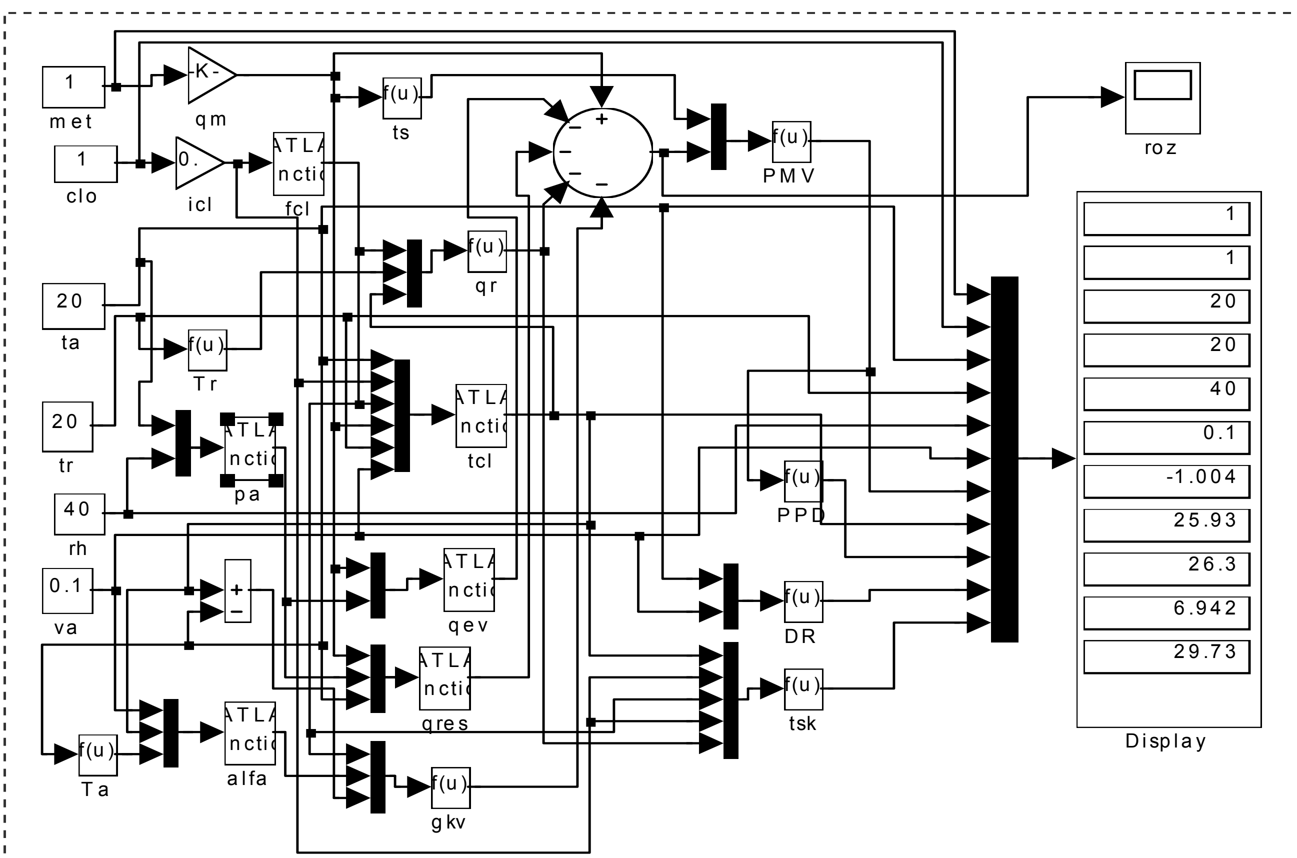

Fig.5 Model of evaluation in the MATLAB-Simulink

ACKNOWLEDGMENT

This work was supported in part by the Ministry of Education, Youth and Sports of the Czech Republic under grant No. MSM 7088352102: “Modeling and control of processes of natural and synthetic polymers”.