MONITORING AND ANALYSIS OF THERMAL CONFORT PARAMETERS IN A LIVING ROOM OF A BUILDING

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Abstract - In this paper, the authors presents the result of the monitoring and analysis of thermal comfort parameters for a residential building. These parameters were obtained using a special equipment for monitoring and data acquisition. In order to obtain concrete results, measurement were done in a 3 rooms flat from the first floor of a residential building situated at around 3,3 m from the ground. For a more accurate evaluation of the thermal comfort level reached in the studied room, specifically in the building envelope elements of the analyzed room-exterior and interior walls. The monitoring equipment was installed in the analyzed room at 1,5 m from the decking and 30 cm from the each walls in the middle of their area. Thus, it has been determined on the interior wall area, the temperature [^{0}C], relative humidity of air in the walls area [%RH] and dew point. Measurements were done during summer time (in June)- over a 24 hours period – thus enabling the moments of time that are exceeded normal, values limits of thermal comfort parameters, this leads to the sensation of thermal discomfort.

Keywords: thermal comfort, building envelope, monitoring and data acquisition, thermal parameters.

1. INTRODUCTION

Since the most people carry 80..... 90% of life in buildings, and they are aimed at satisfying the objective and subjective requirements about vital human functions, enclosed spaces should ensure both the maximum efficiency in performing physical work and the intellectual one, while allowing of carrying out recreational activities, rest and sleep in optimal conditions [3].

Achieving these conditions depends on many factors which influence decisively the felt sensation of comfort, ability of work and regeneration of human body.

The most important requirement of adequate housing in terms of thermal comfort, is that regardless of season and outdoor climate conditions, to provide a good environment inside in which the elements that define comfort to keep within the limits of optimal values.

The design of enclosed spaces taking into account these conditions is a complex problem that can be solved by the plumber engineer and architect, together with psychologists, sociologists and ergonomists. But we must take into account the current trends of rationalization of energy consumption, decisively which influence the optimal values or permissible comfort parameters. In most cases these influences have adverse effects because this criterion leads to inappropriate values in terms of comfort.

Thus, the design of buildings, respectively the inner microclimate it must be the result of a multi-criteria optimization calculations given comfort (technically and psychologically) and energy savings in the same time.

2. THERMAL COMFORT INDEX

The elements which define the thermal comfort of a room are: air temperature, t_i, relative humidity, φ_i , the speed with which air moves inside the room, v_i, the temperature on the inner surface of the construction elements, θ_i.

The manner in which these parameters are perceived by the occupants of a room is subjective and is different depending on: age, health, inside clothing worn, the work they perform, and so on. The concept of technical comfort includes all parameters captured and controled with installations that directly influence human disposal and act on its senses.This includes thermal comfort, acoustic, olfactory and visual. Corresponding percentages of dissatisfied in relation to the comfort provided - 10%, 20%, 30% - enclosed spaces are classified into three categories: A, B and C.

The factors that influence the thermal comfort are [1]:

a. The amount of heat exchanged by the human body convection with ambient air, determined with equation [2]:

$$q_{cv} = \alpha_{cv} \cdot S_0 \cdot (t_0 - t_i)\ [W] \qquad (1)$$

where:
α_{cv} - coefficient of heat exchange by convection, [W/(m^2·K)];
S_0 – the total outer surface of the human body, [m^2];
t_0 - the average surface temperature of the human body, [°C];
t_i - the air temperature in the enclosure, [°C].

b. The amount of heat exchanged by human body radiation with building elements bounding enclosure [2]:

$$q_r = \alpha_r \cdot S_0 \cdot (t_0 - t_{mr})\ [W] \qquad (2)$$

where:
α_r - coefficient of radiant heat exchange, [W/(m^2·K)];
t_{mr} - the average surface temperature of the heaters, [°C].

The value for the coefficient of heat exchange by radiation is given by:

$$\alpha_r = \frac{\left(\frac{T_0}{100}\right)^4 - \left(\frac{T_{mr}}{100}\right)^4}{T_0 - T_{mr}} \cdot C \cdot (1-\varepsilon) \qquad (3)$$

where:
T_0 şi T_{mr} - absolute mean surface temperature of the human body, namely the mean absolute temperature of radiating surface; [K];
C – radiation coefficient of the two surfaces [W/(m²·K)];
ε - caloric radiations absorption coefficient of the air layer between human body and building elements radiating.

c. The amount of heat changed by human body moisture evaporating is determined by the relation [2]:

$$q_{ev} = c \cdot r \cdot (p_s - p) \cdot \frac{p_{B0}}{p_B} \cdot S_0 \qquad (4)$$

where:
c - evaporation coefficient dependent on airflow over the inner;
r – latent heat of vaporization of the water at the average temperature of the surface of the human body t_0;
p_s the saturation pressure of the average temperature of the human body t_0 ;
p – the partial pressure of water vapor in the air;
p_B– barometric pressure;
p_{B0} – normal barometric pressure.

d. The amount of heat generated by the human body is mainly dependent on the intensity of the work being done (table 1).

Table 1. Quantity of heat generated by the human body [2]

Type of activity		Quantity of heat generated by the body, [W]
	Sleep	73
	Seated, quiet	116
Light work	Seated, moderate movements	133 ÷ 160
	Standing, light work at machine or bench	160 ÷ 190
Moderate work	Seated, strong movements of the arms and legs	190 ÷ 237
	Standing, light work at machine or bench and briefly displacements	190 ÷ 220
	Standing, moderate work at machine or bench and briefly displacements	220 ÷ 293
	Displacements from one place to another by lifting, pulling or pushing moderate	293 ÷ 410
Hard work	Hard work intermittent lifting, pulling or pushing	440 ÷ 586
	Continues hard work	586÷ 704

The sensation of thermal comfort is defined as the conscious expressing satisfaction with the thermal environment and which valuation is performed using subjective scale of comfort with seven levels (5): +3 (very hot); 2 (hot); +1 (slightly warm); 0 (neutral); -1 (chill); -2 (cool); -3 (cold) [4].

$$B = C + 0{,}25 \cdot (t_i + t_{mr}) + 0{,}1 \cdot x - 0{,}1 \cdot (37{,}8 - t_i) \cdot \sqrt{v_i} \qquad (5)$$

where:
C - constant that has the value -9.2 during the cold and -10.6 during the warm period.

The literature defines as sensory temperature (or average temperature felt) – t_{sz} the fictitious indoor air temperature of a hypothetical site where heat exchange between human body and environment is made by convection. Achieving thermal comfort requires equalization of heat exchanged by the human body with the output heat from the body, which requires sensory temperature reaches a certain value called **comfort temperature– t_c:**

$$t_{sz} = t_c \; [°C] \qquad (6)$$

The amount of heat developed by the human body are dependent on the intensity of work done, and therefore comfort temperatures are also dependent on the type of work done by human in the enclosure (figure 1).

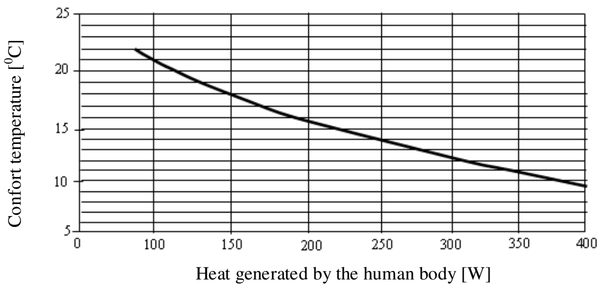

Figure 1. Confort temperature variation relative to the intensity of work [2]

3. COMFORT INDEX EVALUATION

To appreciate how the interior microclimate factors contribute to thermal comfort, sensory temperature should be expressed by all four factors. One of the relationships which allow determining the sensory temperature is [4], [5]:

$$t_{sz} = 0{,}431 \cdot t_i + 0{,}408 \cdot t_{mr} - 0{,}141 \cdot \sqrt{v_i} \cdot (37{,}8 - t_i) + 0{,}182 \cdot \varphi_i \cdot p_s - \cdot 0{,}328 \; [°C] \qquad (7)$$

where:
φ_i – relative inner humidity, [%];
p_s – the saturation vapor pressure of water at the inner temperature t_i, [bar];
v_i – current velocity of the inner air, [m/s].
Mean radiant temperature is determined by the relation 8 for all construction elements which border the enclosure [5]:

$$t_{mr} = \frac{\sum S_i \cdot t_{p,i}}{\sum S_i} \ [°C] \qquad (8)$$

where:
t_{pi} - the temperature of the inner face of the building element "i" that abuts the enclosure and has the surface S_i, [°C].

Typically, the relative humidity varies restricted, and its effect on sensory temperature can be neglected. In this situation, sensory temperature is determined with the relationship [4], [5]:

$$t_{sz} = 0{,}522 \cdot t_i + 0{,}478 \cdot t_{mr} - 0{,}205 \cdot (37{,}8 - t_i) \cdot \sqrt{v_i} \ [°C] \qquad (9)$$

In the case of accommodation spaces, both the relative humidity varies restricted and the inner streams of air speeds with low values (v_i<0,2 m/s). Under these conditions, the heat exchanged by human with the environment can be written as:

$$q_s = \alpha_{cv,ev} \cdot S_0 \cdot (t_0 - t_i) + \alpha_r \cdot S_0 \cdot (t_0 - t_{mr}) + q_{ev} \ [W] \qquad (10)$$

where:
$\alpha_{cv,ev}$ - - transfer coefficient of heat that cumulative effect of convection and evaporation.

Thermal comfort will be achieved when the equality is fulfilled, namely when:

$$t_{sz} = \frac{(t_i + t_{mr})}{2} = t_C \qquad (11)$$

Romanian Standard 7730/1997 (identical to the international standard ISO 7730/1994) used both for assessing the quality of thermal comfort (PMV index) and the number of unsatisfied of the made conditions (PPD index) [2], [4].

PMV index (relation 12) is an indicator that allows the assessment to achieve thermal comfort, on the seven levels of comfort scale, depending on the intensity of the human work, for his coverage of clothing and inner environment parameters.

Estimate the likely number of people dissatisfied with conditions is performed using PPD index (percentage predictably unhappy, relationship 16).

$$\begin{aligned} PMV = & \left(0{,}303 \cdot e^{-0{,}036 \cdot q_0} + 0{,}028\right) \cdot \{(q_0 - q_R) - 3{,}05 \cdot 10^{-3} \cdot [5733 - 6{,}99 \cdot (q_0 - q_R) - p_a] - \\ & - 0{,}42 \cdot [(q_0 - q_R) - 58{,}15] - 1{,}7 \cdot 10^{-5} \cdot q_0 \cdot (5867 - p_a) - 0{,}0014 \cdot q_0 \cdot (34 - t_i) - \\ & - 3{,}96 \cdot 10^{-8} \cdot S_h \cdot \left[(t_h + 273)^4 - (t_{mr} + 273)^4\right] - S_h \cdot \alpha_c \cdot (t_h - t_i)\} \end{aligned} \qquad (12)$$

with:

$$\begin{aligned} t_h = & 35{,}7 - 0{,}028 \cdot (q_0 - q_R) - R_h \cdot \{3{,}96 \cdot 10^{-8} \cdot S_h \cdot [(t_h + 273)^4 - \\ & - (t_{mr} + 273)^4] - S_h \cdot \alpha_c \cdot (t_h - t_i)\} \end{aligned} \qquad (13)$$

$$\alpha_c = \begin{cases} 2{,}38 \cdot (t_h \cdot t_i)^{0{,}25} & - \text{pentru } 2{,}38 \cdot (t_h \cdot t_i)^{0{,}25} > 12{,}1 \cdot \sqrt{v_i} \\ 12{,}1 \cdot \sqrt{v_{ar}} & - \text{pentru } 2{,}38 \cdot (t_h \cdot t_i)^{0{,}25} < 12{,}1 \cdot \sqrt{v_i} \end{cases} \qquad (14)$$

$$t_h = \begin{cases} 1{,}00 + 1{,}290 \cdot R_h & - \text{pentru } R_h \le 0{,}07 \ [(m^2 \cdot °C)/W] \\ 1{,}05 + 0{,}645 \cdot R_h & - \text{pentru } R_h > 0{,}078 \ [(m^2 \cdot °C)/W] \end{cases} \qquad (15)$$

$$PPD = 100 - 95 \cdot e^{-(0{,}03353 \cdot PMV^4 - 0{,}2179 \cdot PMV^2)} \qquad (16)$$

4. THERMAL COMFORT INDEX USING ASSESSMENT MONITORING EQUIPMENT

Inside a building, even if it is not provided with heating, ventilation or air conditioning, values and variations of the temperature, humidity or the air speed inner currents are different from the outside, being a distinct climate, microclimate known or indoor climate. The differences are due to the thermal inertia of the building.

In order to assess the thermal comfort index for residential building is used the equipment "*Multimetrix DL53*" (figure 2) based on the real-time monitoring software for the main parameters of thermal comfort in different environmental conditions..

Thus the application allows the monitoring and the acquisition of values for the following parameters:

- temperature (-40 ÷ +70 ºC);
- umiditate relativă (0 la 100%RH cu o precizie de ±3%RH);
- punct de rouă.

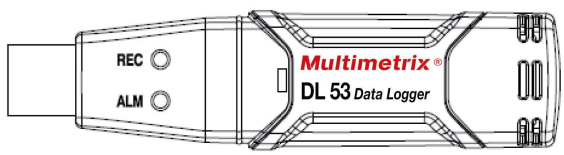

Figure 2. Monitoring equipement for confort parameters "Multimetrix DL53"

All recorded values by the device are shown in graphical form (figure 3) with the possibility of saving as text, in photos form or in tabular form in Excel (figure 4).

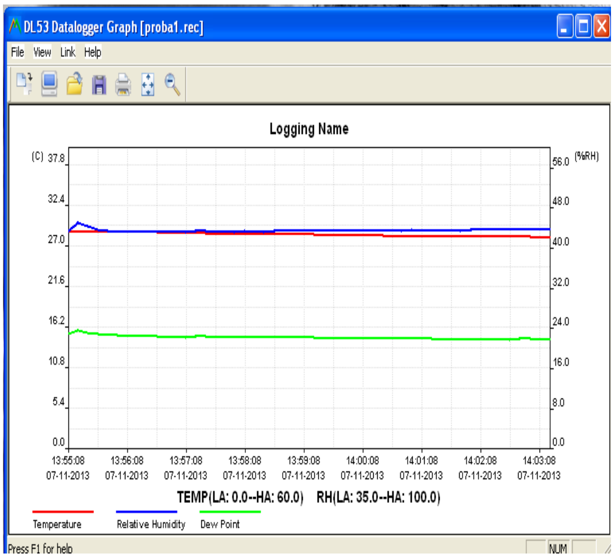

Figure 3. Playing graphical from of the monitored parameters

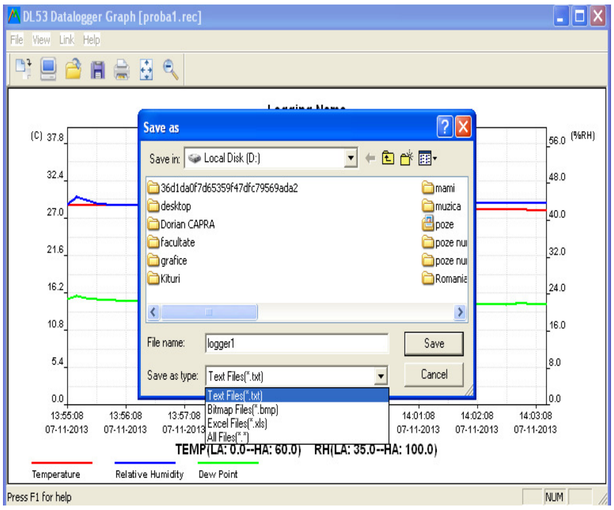

Figure 4. Saving possibilities of the monitored parameters

Measurements were performed in a room in an apartment with 3 rooms (Figure 5) located on the 1st floor of a building, about 3.3 meters altitude to earth and having a floor area of 72.86 m^2.

For measurements inside the monitored room, the device was placed on a stand at a height of 1.5 meters of the total of 2.5 meters of room, at a distance of 30 centimeters from the wall.

In the case of measurements outside of the building, the unit was placed on a support fixed at a distance of 20 centimeters to exterior wall.

The room monitored in terms of comfort parameters was the dining room, being used to determine both the inner surfaces of the vertical walls (two external and two inner) defining the four geographical room and the exterior surfaces of the two outer walls .

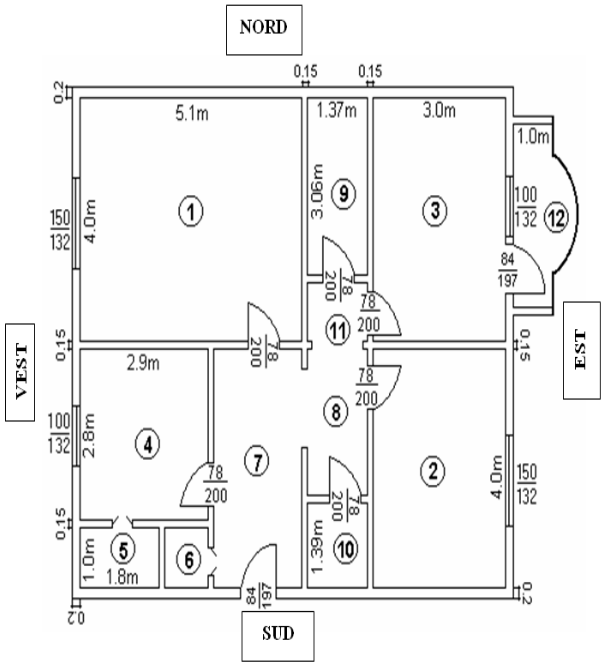

Figure 5. Monitored apartment layout: 1 - dining room; 2 – bedroom 1; 3 – bedroom 2; 4 - kitchen; 5 – pantry; 6 – storage; 7 – hall; 8 – lobby 1; 9 – bathroom 1; 10 – bathroom 2; 11 – lobby 2; 12- balcony

5. INTERPRETATION OF RESULTS AND CONCLUSIONS

Perception and appreciation of the basic elements of comfort by humans are influenced by some psychological factors, but also human development and psychological balance are closely linked with the environment. So, between psychological and technical comfort is a reciprocal relationship. Human psyche depends, however, from independent factors such as age, sex, etc., which influence the level of comfort and technical assessment. So, pleasant feeling that may occur resulting optimum technical parameters and psychological comfort.

The monitoring of parameters of comfort to the interior surfaces of the walls of the dining room have been made on the intervals of time of about 24 hours, trying in this way to highlight them for various values of changes in temperature and humidity of the outside air.

From measurements performed the following resulted:

I. In the dining room wall facing south direction measurements were made between 10.06.2013-14:25 and 11.06.2013-12:35 time (figure 6) observing that:

- relative humidity ranged from 50.6% to 64.6%;
- inner temperature varied between 26˚ C and 26.2 ˚ C which resulted in variations in the dew point temperature between 16.1 ˚C and 19.3˚C;
- most of the time the measurements were made, the sensation felt over a distance of 30 inches from the inner wall of the dining room oriented in a southerly direction is thermal discomfort (feeling muggy - 64.6% moisture and temperature 25,3˚C - figure 7) with a maximum felt at 02:45 on 11.06.2013.

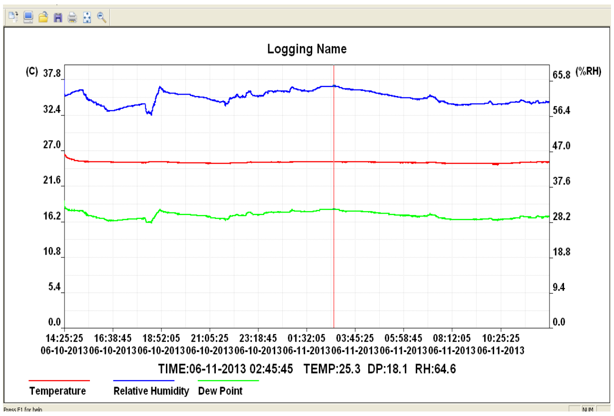

Figure 6. The variation of the monitored parameters for the inner wall of the dining room oriented on South direction

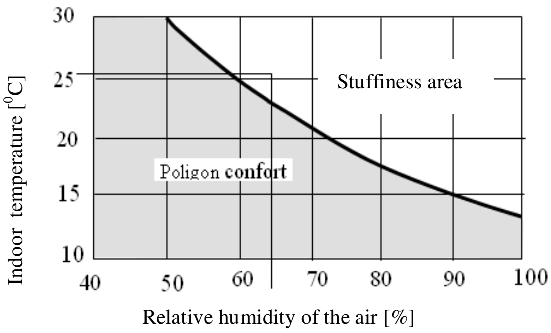

Figure 7. The sensation felt by the human body near the inner wall of the dining room oriented on South direction

II. In the dining room oriented north wall measurements were performed within the time 05.06.2013-20:36 and 07.06.2013-02:36 (figure 8) observing that:

- relative humidity ranged from 49.9% to 65.2%;
- inner temperature varied between 23.5˚C and 26.0˚C which led to changes in dew point temperature between 13.4˚C and 17.0˚C;
- only moment of time in the range monitored the sensation felt in the right outer wall of the dining room facing the north, it is thermal discomfort is 23:00 o'clock when inner temperature reaches 24.0˚C, and the humidity inner is 65.2% (figure 9).

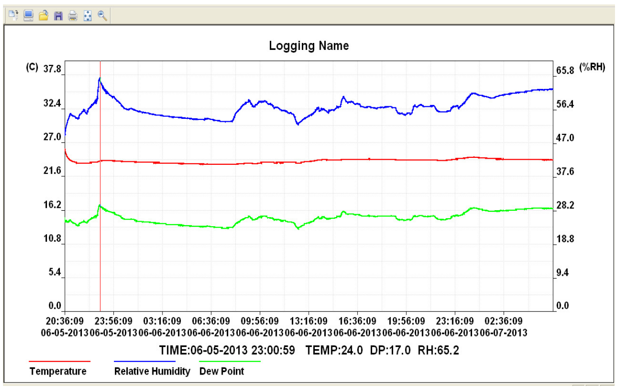

Figure 8. The variation of the monitored parameters for the outer wall of the dining room oriented on North direction

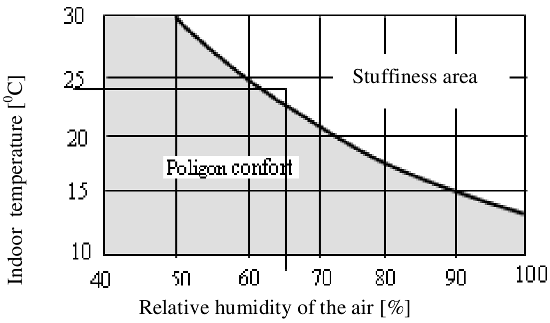

Figure 9. The sensation felt by the human body near the outer wall of the dining room oriented on North direction

III. In the dining room wall facing west direction measurements were performed within -11.06.2013-18:44 until 12.06.2013-22:30 (figure 10) observing that:

- relative humidity ranged from 64.0% to 73.3%;
- inner temperature ranged between 24.0˚C and 25.8˚C which resulted variations in the dew point temperature from 17.2˚C to 19.9˚C;
- as in the case of the wall facing south direction for the entire period that the measurements were sensation is felt in the wall to a maximum muggy registered on 12.06.2013 at 13:14 (figure 11).

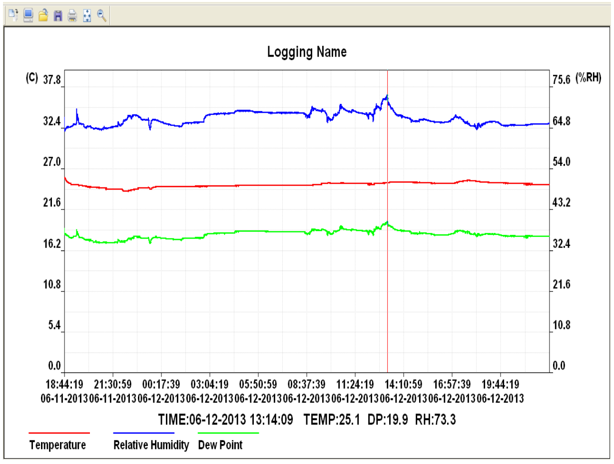

Figure 10. The variation of the monitored parameters for the outer wall of the dining room oriented on West direction

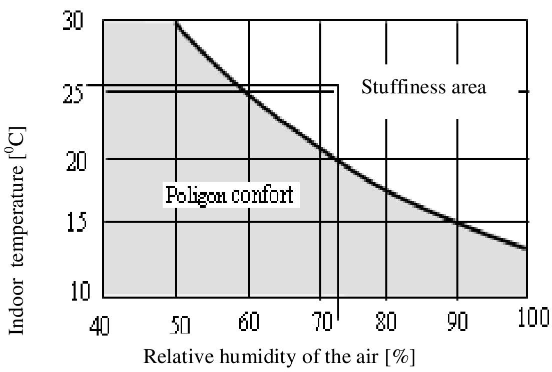

Figure 11. The sensation felt by the human body near the outer wall of the dining room oriented on West direction

IV. In the dining room wall facing east direction measurements were made between 17.06.2013-13:28 time, and 18.06.2013-18:44 time (figure 12) observing that:

- relative humidity ranged from 66.1% to 73.9%;
- inner temperature varied between 27˚C and 28.2˚C which resulted variations in the dew point temperature between 19.5˚C and 22.1˚C;
- facing the inner wall of the living room in an easterly direction for the entire period of measurement feeling felt by the human body, the wall is one of a peak muggy on 18.06.2013-4:53 o'clock (figure 13).

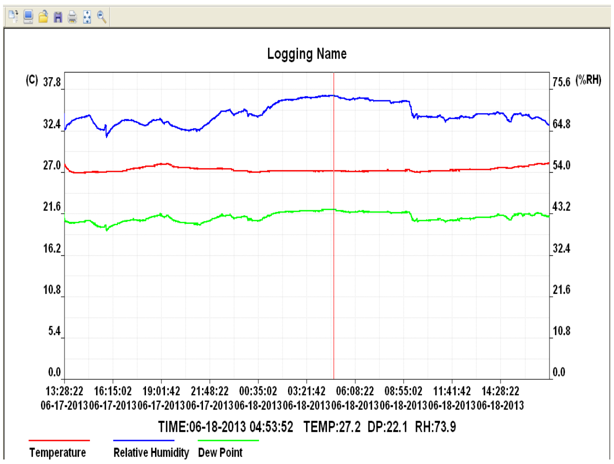

Figure 12. The variation of the monitored parameters for the inner wall of the dining room oriented on East direction

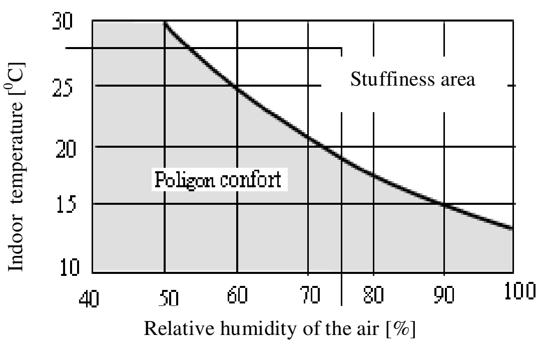

Figure 13. The sensation felt by the human body near the inner wall of the dining room oriented on East direction

V. In the case of monitoring parameters outside the building, the exterior wall of the living room facing the west, the following resulted (figure 14):

- relative humidity of outside air varied between 61.3% and 79.9%;
- outdoor air temperature varied between 5.1˚C and 10.1˚C which led to changes in dew point temperature between 0.9˚C and 4.4˚C;
- to the outer wall of the living room facing west direction maximum recorded value of 79.9% relative humidity at a temperature of 5.4˚C and the dew point temperature of 2.1˚ C was reached on 21.01.2013 at 23:30.

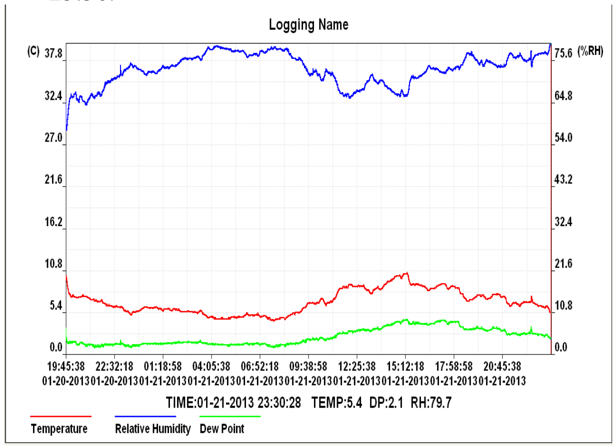

Figura 14. The variation of the monitored parameters for the outer wall of the dining room oriented on West direction (out of the building)

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