A FOUR EQUATIONS REGRESSION MODEL FOR SIMPLIFIED CALCULATIONS OF THE THERMAL COMFORT LEVEL IN MODERATE ARTIFICIAL ENVIRONMENTS.

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The applicability of the P.O. Fanger's theory becomes complex when high intensity sources are present in the ambient under examination. In these cases, in fact, due to the difference between air ambient and mean radiant temperatures, the evaluation of the Predicted Mean Vote (PMV) can't be conducted by means of the usual tables and graphs provided within the method.

In the aim of overcoming this problem we have developed a simple set of equations able to get the computation of the PMV.

The method is especially devoted to calculations by means of personal computers.

INTRODUCTION

As it is well known, the P.O. Fanger theory represents one of the most useful and worldwide employed tools for the evaluation of the thermal comfort conditions of thermal moderate artificial environments (that is the ambients where it is possible to achieve the thermal comfort conditions for the occupants), due to its feasibility and its fitness to architectural purposes analysis.

It has been recently adopted by the ISO standards (1). In addition in the past year, an Italian rule for the evaluation of the indoor thermal comfort situations, has essentially taken in the guidelines of the Fanger method.

It lies on the computation of the thermal balance on a human body in a given confined environment, expressed by a characteristic double equation (2) that, due to its popularity among the scientific community, will not here reported and described. As final result, it provides the value of the "predicted mean vote" (PMV), that expresses the judgement of a person with respect to the artificial confined ambient where he is supposed to stay.

Notoriously, it's possible to employ the method by means of tables, as well by means of a comprehensive set of graphs in the case of mean radiant temperature equal to air temperature.

PMV COMPUTATION DEPENDING ON MEAN RADIANT TEMPERATURE

The mean radiant temperature represents the uniform temperature of an enclosure where an occupant would exchange the same amount of radiant heat as in the actual non-uniform environment.

Usually, in the building studies, the value of the mean radiant temperature can be reasonably assumed equal to that one of the air ambient temperature. But if one wants to take into account the presence of the solar radiation on the human body (that modifies remarkably the thermal balance (3)) or the presence of any other high intensity radiant sources (like infrared heaters or lighting fixtures), the mean radiant temperature value does differ from that one of the air temperature.

In this case the Fanger's methodology can't be applied without deep operations on the basic equations: in any case the simple use of tables and graphs is not recommended.

THE REGRESSION EQUATIONS

In order to simplify the procedures for the calculation of the PMV and to make possible the utilization of easy personal computer programs, we have developed four regression equations, depending on the effective subjective and environmental parameters.

Using a computer code developed by some of the authors and based on the Fanger theory, we have generated the following best fit equation for the computation of the PMV:

$$PMV = a_1 \, SHL + a_2 \, t_a + a_3 \qquad [1]$$

where ta is the current air ambient temperature (°C) and SHL is the heat load (W/m^2) that will be defined later.

The parametric coefficients a_i, depending on the relative air velocity that hits the person inside the room (m/s), have the following structure:

$$a_1 = i \, v^2 + j \, v + k \qquad [2]$$

$$a_2 = l \, v^2 + m \, v + n \qquad [3]$$

$$a_3 = x \, v^2 + y \, v + z \qquad [4]$$

In the equation [1] SHL is the heat load on the human body that takes into account the presence of high intensity radiant sources and the subsequent modifications of the mean radiant temperature, that in the following will be indicated as MRT. In fact:

$$MRT_{modified} = [Ta^4 + SHL/(A_{eff} \, e_p \, \sigma)]^{0.25} \qquad [5]$$

and:

$$SHL = A_p \, a \, q_{ir} \qquad [6]$$

In the previous equations, other than SHL, the simbols are those introduced and defined by P.O. Fanger (2), that provides a large set of useful values for each parameter. In particular, e_p is the emissivity of the human body, σ is the Stephan Boltzman constant, A_{eff} is the effective radiation area, T_a is the absolute air temperature (K), a is the absorptance of the outer surface of the person, A_p is the projeted area, and q_{ir} the mean radiant flux density (W/m^2).

It's here important to note that q_{ir} includes the solar radiation falling on the human body inside a room. This is relevant, of course, for analysis regarding the passive solar buildings where solar radiation is supposed to play a determinant role.

Table 1 reports the values of the a_i coefficients that we have found for metabolic rates ranging from 48 to 150 W/m². The table is valid for seated persons dressed with a clothing ensamble corresponding to a total thermal resistance of 0.5 clo, and for a relative air humidity of 0.5.

Metabolic Rate [W/m²]	Coefficients a_i								
	a_1			a_2			a_3		
	i	j	k	l	m	n	x	y	z
48	0.00505	-0.01591	0.03251	-0.07545	0.22900	0.44377	2.59840	-7.83404	-11.95877
58	0.00397	-0.01256	0.02583	-0.05532	0.17237	0.35991	1.88859	-5.85214	-9.27499
70	0.00339	-0.01046	0.02094	-0.05063	0.15071	0.28754	1.66454	-4.97501	-6.95783
80	0.00296	-0.00914	0.01832	-0.04417	0.13180	0.25265	1.45539	-4.43048	-4.79561
90	0.00272	-0.00836	0.01661	-0.04065	0.12052	0.22968	1.32018	-3.90815	-4.98702
100	0.00259	-0.00789	0.01550	-0.03860	0.11360	0.21471	1.23580	-3.63526	-4.40060
110	0.00250	-0,00757	0.01478	-0.03768	0.10983	0.20491	1.21358	-3.47464	-3.95279
120	0.00250	-0.00748	0.01434	-0.03738	0.10789	0.19863	1.15584	-3.34942	-3.59286
130	0.00250	-0.00742	0.01404	-0.03687	0.10607	0.19507	1.12634	-3.25314	-3.29834
140	0.00250	-0.00736	0.01386	-0.03668	0.10511	0.19303	1.10632	-3.18431	-3.03825
150	0.00247	-0.00725	0.01369	-0.03645	0.10430	0.19213	1.08553	-3.12055	-2.80459

TABLE 1 Values of the a_i coefficients of the regression equations.

VERIFICATION OF THE METHOD

In order to verify the reliability of the proposed equations we have compared the PMVs calculated with our regression method with the PMVs found by means of the application of the extensive Fanger theory, in presence of high intensity sources in the considered ambient.

Figures 1, 2 and 3 report that comparisons, respectively for the cases of indoor air temperatures equal to 23, 26 and 29 °C. The curves are plotted for air velocities of 0.1, 0.3 and 0.5 m/s. The first value of the relative air speed is typical of rooms subjected to natural ventilation, while other values are often recovered in ambient equipped with mechanical climatisation systems. Figure 4 describes the behaviour of the PMVs as a function of the metabolic rate (M/A_{DU}), for the case of a total effective heat load on the human body of 50 W/m².

The accordance appears fairly good.

CONCLUSIONS

The simple method here presented enables the computation of the predicted mean vote referring to confined moderate environments, for seated persons, that is the posture more often occuring in office buildings, where people occupies for a long lapse of time the same position in the room.

The peculiarity of the method lies on the possibility of evaluating the thermal comfort conditions even in presence of high intensity radiant sources, when the Fanger's method becomes much more complex.

The set of regression equations, along with the table of coefficients, can be easily entered, starting from the knowledge of the actual indoor air ambient temperature, the relative air velocity, the mean radiant density flux generated by infrared heaters or referred to the solar radiation. Moreover the activity level of people can be chosen.

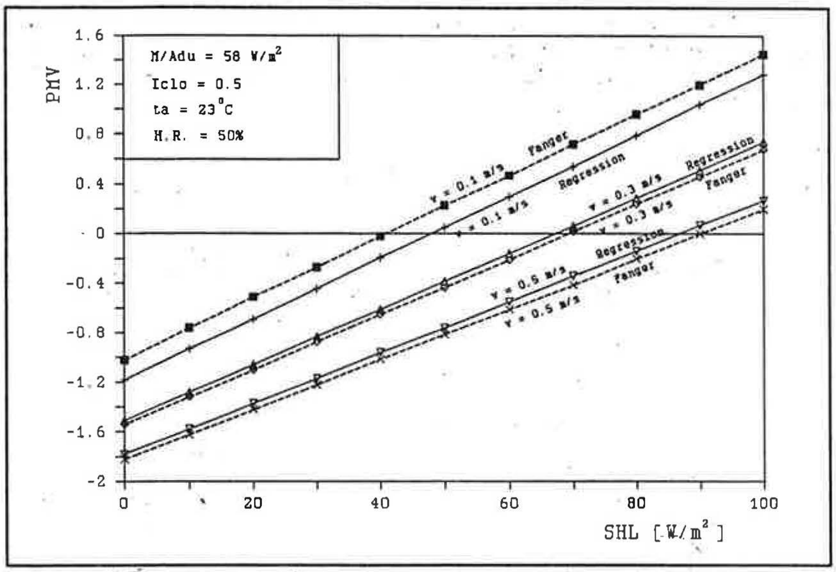

Figure 1 - Comparison between the PMVs calculated with the regression equations and those calculated with the application of the extensive Fanger's theory, as a function of the heat load. Case of air temperature=23°C.

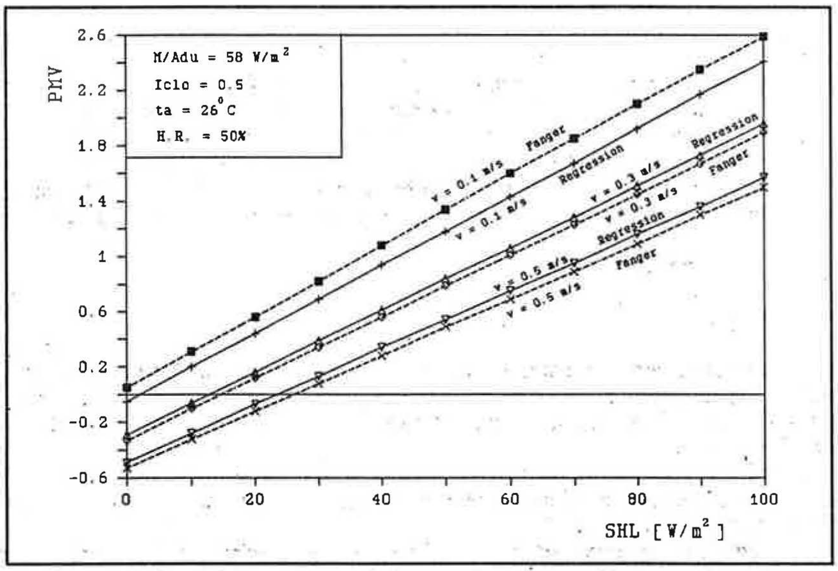

Figure 2 - Comparison between the PMVs calculated with the regression equations and those calculated with the application of the extensive Fanger's theory, as a function of the heat load. Case of air temperature=26°C.

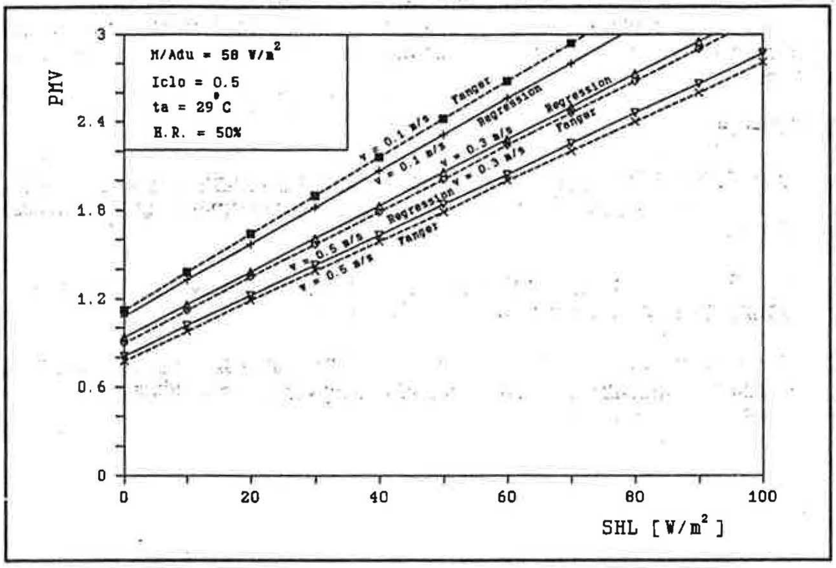

Figure 3 - Comparison between the PMVs calculated with the regression equations and those calculated with the application of the extensive Fanger's theory, as a function of the heat load. Case of air temperature=29°C.

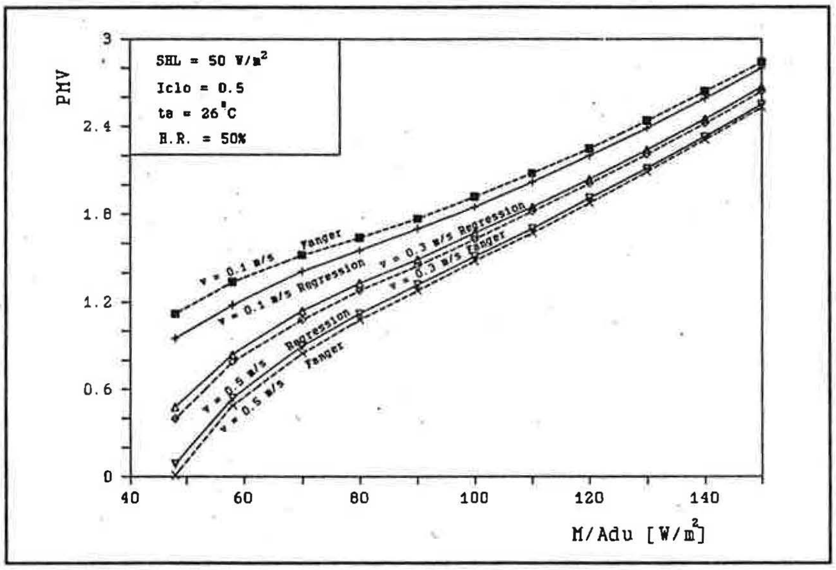

Figure 4 - Comparison between the PMVs calculated with the regression equations and those calculated with the application of the extensive Fanger's theory, as a function of the metabolic rate.

Through all the research, the relative humidity is supposed at the value of 0.5.
At this stage of our study we have selected only a total thermal resistance of 0.5 clo.
Another relevant feature of this methodology is its suitability to personal computer calculations.

REFERENCES

1. ISO 7730 (1984) Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. International Standard.

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3. A. Giaccone, E.A. Parrino, G. Rizzo (1986) The influence of indoor solar radiation distribution in a room on thermal comfort evaluations. Proceedings of the 10th CIB Congress, Washington, DC.