Comfort evaluation: the relevance of the transition time

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ABSTRACT: Comfort evaluation of indoor spaces is generally done with the well know Fanger's method, which considers a static situation and average values for the variables of the thermal balance equation. However, the reality is quite different and the dynamic effects are often dominant over the sensation of comfort that users feel, for instance, when entering in a conditioned space from the street: The first impression is different from what is sensed after some time in the space. With the addition of a transition term, the Fanger's equation for the PMV can better approximate the reality, but it is important to determine the time dependence of the feeling of the users after changes, in order to evaluate the empiric coefficient of this additional term. Field studies will be conduced to this effect, in different climates and countries: Mexico, Italy and Spain. Expected results are the definition of time dependence and the coherence with the predicted values obtained from the use of the additional terms in the Fanger's equation. The results of previous Mexican analyses have demonstrated the necessity of another correction term, dependent on climatic adaptation. The final form proposed for the equations to evaluate comfort has points in common with a PID processor, where the integrative term is the adaptation correction and the derivative term is the dynamic correction.

Keywords: users, comfort, pmv

1. Introduction

Comfort evaluation of indoor spaces is a very important need of the architectural project. Normally, this is conducted with the method developed by Fanger in the 70s. This method is based on the thermal balance of the human body.

Other methods have been proposed before and after the Fanger's equations publications, but today it is very common to refer to the PMV index of the Fanger's method. All these evaluations use average values, or, it can be said, static conditions. A dynamic method of calculation is also an urgent need.

The comfort sensation of a person moving from one space~~s~~ in to another could be evaluated with a simple derivative correction in the formulas used to assess comfort. The aim of this work is to propose this correction term for the Fanger's standard method. Possible applications of the new formula will also be discussed. The final proposed form of the equations will have the form of a PID processor, well know instrument to assess physical phenomena with an internal control.

Architects may think that evaluations like these are not very important, but everyone experiments all days the impact of situations like feeling cold in a restaurant, very warm in a metro station, or when shopping in winter one has to enter in a large mall with very uncomfortable temperatures for the clothes he is wearing.

2. Methodology

The Fanger's equations evaluate the comfort based on six variables [1]: air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate and clothing. The variables are inserted into an energy per unit time balance equation (1):

$$H - E_d - E_{sw} - E_{re} - L - K = S \qquad (1)$$

where H is the internal heat production in the human body, E_d is the heat loss by water vapour diffusion through the skin, E_{sw} is the heat loss by evaporation of sweat from the surface of the skin, E_{re} is the respiration latent heat loss, L is the ~~dry~~ respiration sensible heat loss, K is the heat transfer from the skin to the outer surface of the clothed body, and S represents the energy that the human body would have to loose or receive in the unit time to keep the energy balance while feeling comfortable, that is, assuming for the skin temperature and for E_{sw} the comfort values. This value is directly connected with the PMV (Predicted Mean Vote) concept [1] expressed in equation (2):

$$PMV = \left(0.352 e^{-0.042 \frac{M}{A_{Du}}} + 0.032 \right) S \qquad (2)$$

where S is the result of equation 1 in comfort conditions and M/A_{Du} is the metabolic power for body surface unit. The difference between M and H is that M is the total power production of the metabolism, where H is the heat production of the metabolism, the difference being mechanical work done by the body.

For a dynamic evaluation, a first approach can be

$$\| S' \| = \| S \| + \left\| \frac{\delta S}{\delta t} \right\| \Delta \qquad (3)$$

where the derivative term is 0 in static conditions. The value of Δ to be used will be obtained from field studies, and probably it depends on the user's expectations. A first tentative value could be set at 60 s. An alternative method is the ACT program, developed by Isalgué and Serra [2]. The variables to be calculated are in this case the equivalent temperature (that takes into account the ambient) and a desired temperature (that takes into account the expectations of the users). ACT and PMV results are something different, because of the different weight of the single factors. Future works will compare the results obtained with these and other methodologies.

3. Results

With these equations we can simulate some dynamic situations, but all the results have to be confirmed by field studies. At the moment, we are doing the first experiment, with the values of the parameters of Table 1 for the internal space. In all the tables it is used the Met unit (1Met=58 W/m^2).

Table 1: Internal values of the parameters

Ta (°C)	Tmr (°C)	Vair (m/s)	HR (%)	Met	Clo
18	20	0,2	35	1,0	0,8

The values of the external ambient parameters will only be known the day of the experiment, but let's suppose they are as shown in Table 2.

Table 2: External values of the parameters (supposed)

Ta (°C)	Tmr (°C)	Vair (m/s)	HR (%)	Met	Clo
24	24	1	35	1,0	0,8

Expected results have to show the very different behavior between the pmv and the adjusted pmv. The predicted behavior is described in Figure 1.

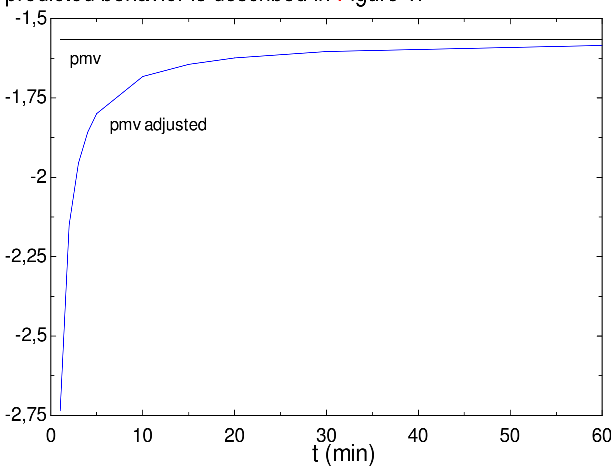

Figure 1: PMV and PMV adjusted of the prediction

In the Mexican case it will be considered the adaptation term proposed by the same Fanger for hot dry climates [3].

The field study will be conducted this way: a group of 40 students is divided in two groups of 20. All students are asked to mark down their vote. This action is done outdoor. One group is then moved inside a classroom, while the other stays outside for 20 minutes, then joins the other group inside. All students vote for the second time, and are asked to vote every minute, during 15 minutes. After, they vote every 5 minutes, during 45 minutes. The-experiment takes 1 hour and half in total. The votes are expressed in the PMV scale, from -3 to 3, were -3 is very cold, -2 is cold, -1 is cool, 0 is the neutrality, 1 is little warm, 2 is hot and 3 is very hot.

The predicted results of the equations taken into consideration here have been computed using the EES program.

4. Applications

A general approach, valid in all cases, would be very useful. While working on this hypothesis, some specific case can be analyzed, which will be evaluated in the future.

One important application would be the determination of the comfort temperature in the hallways of commercial centers. There, in winter, shoppers typically wear clothes and have metabolic rates different from the ones of salespersons.

Obviously, the temperature in the hallways should be different from the temperature in the shops. In fact, often commercial centers are kept at a uniform temperature in all the structure.

With the proposed method, it is possible to underline that temperatures have to be different, and to evaluate the value for the temperature in the hallways. Table 3 shows the supposed values for people working in a center.

Table 3: Typical values of the parameters for people working in a commercial center

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
20	24	0,2	30	2,0	0,8

Table 4 shows the supposed values for people shopping in a center (winter conditions).

Table 4: Typical values of the parameters for people shopping in a commercial center in winter

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
20	24	0,2	30	1,6	1,3

Table 5 shows the supposed external values.

Table 5: Supposed external values of the parameters for people shopping in winter

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
0	10	1	30	2,0	1,3

Figure 2 compares the PMV working and shopping people, considering the correction term and not considering it.

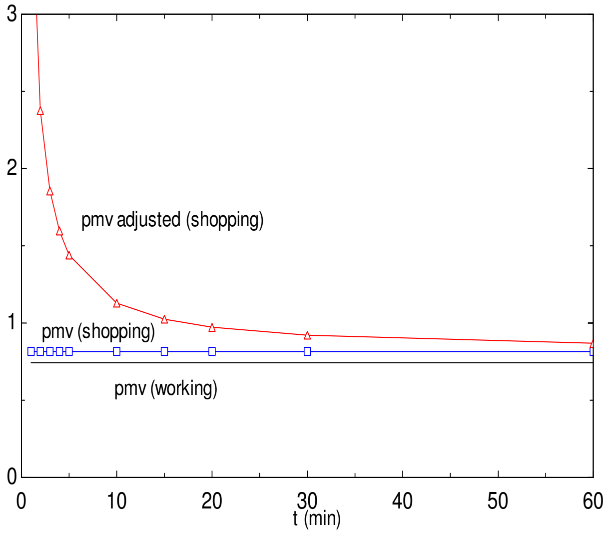

Figure 2: PMV and PMV adjusted for people working and shopping in a commercial center in winter

By setting the hallway temperature at 15 ºC instead of 20, and Tmr at 18 ºC instead of 24, we obtain the results of Figure 3, which show that comfort conditions for shoppers entering the shopping center from the outside are reached much more rapidly.

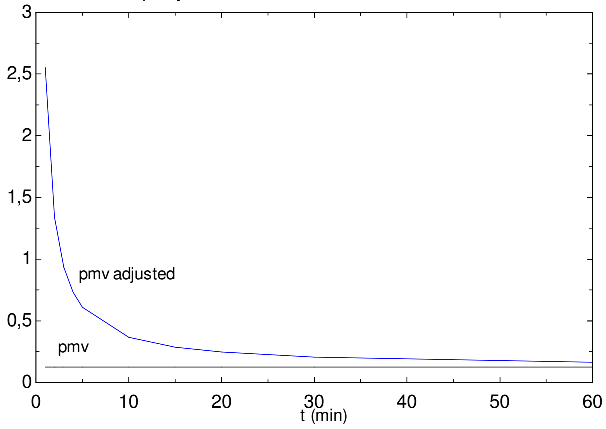

Figure 3: PMV and PMV adjusted for people shopping in a commercial center with a hallway temperature of 15 ºC

Another application can be that of summer air conditioning in restaurants. Conditions can range from very uncomfortable near the vents, to generally uncomfortable for people coming from the supposed hot outside conditions. Table 6 shows the values of the parameters for people sitting in a restaurant in summer. Table 7 shows the typical external values in summer. Figure 4 shows the PMV of people coming from outside, with and without the correction term.

Table 6: Typical values of the parameters for people sitting in a restaurant in summer, with air conditioning

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
24	30	0,2	30	1,0	0,6

Table 7: Supposed external values of the parameters in summer

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
30	30	0	50	1,5	0,6

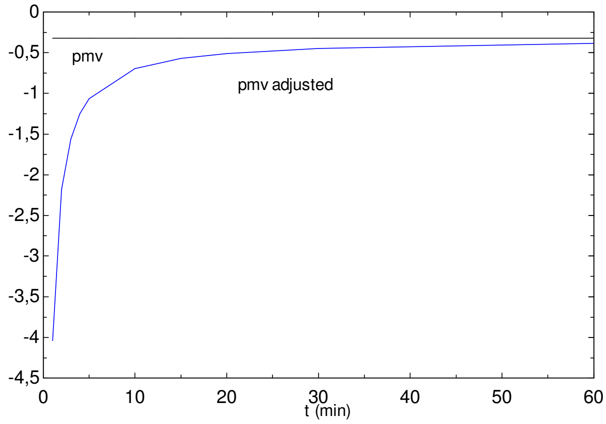

Figure 4: PMV and PMV adjusted in a restaurant with air conditioning

To make a comparison, we analyze the situation of a restaurant with a shaded outdoor space. Values of the parameters are shown in Table 8.

Table 8: Typical values of the parameters in a restaurant with a shaded outdoor space

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
28	26	0,3	50	1,0	0,6

Figure 5 shows the PMV obtained in this condition. It has to be noted that the sensation of comfort is better than in the previous situation. The effect of air conditioning in a restaurant is rather negative, both from the energy and the comfort point of view.

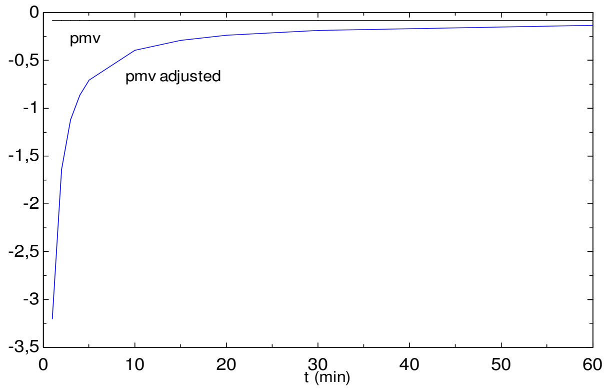

Figure 5: PMV and PMV adjusted for a natural conditioning restaurant

The last application we consider is a subway or metro station. There, a normal evaluation shows that the situation is not good, but an evaluation conducted considering the addition term shows that it is even worse. Clearly, it is not simple to solve the problem of metro stations: people are changing environment very rapidly, from warm to hot and from hot to very cold. A possibility can be higher natural ventilation of the stations, and the reduction of the set temperature inside the trains to values nearer to external temperature. Table 9 presents the initial condition, for example in spring. Table 10 shows the values inside of the passageways of the station.

Table 9: Supposed values of parameters in spring

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
24	26	0,6	40	1,6	0,8

Table10: Typical values of the parameters in the passageways of the station

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
28	30	0,3	60	2,0	0,8

Figure 6 shows the first step of the transition, from the outside to the corridors. Users feel very warm during the transition.

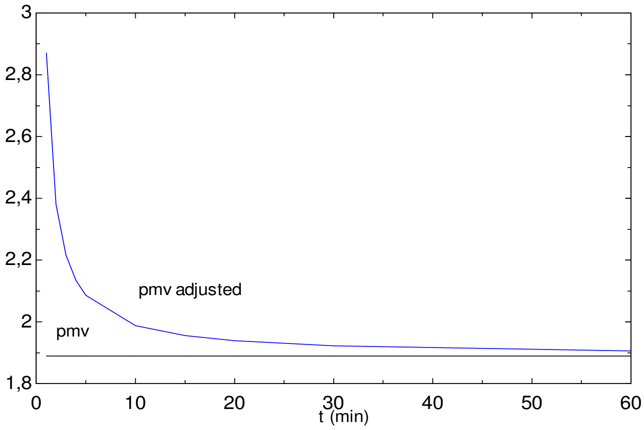

Figure 6: PMV and PMV adjusted for a person entering in a corridor of the metro station

Table 11 shows the values of the parameters inside the trains.

Table 11: Typical internal values of the parameters inside the trains

Ta (ºC)	Tmr (ºC)	Vair (m/s)	HR (%)	Met	Clo
20	24	0,3	30	1,0	0,8

Figure 7 shows the second step of the transition, from the corridors to the metro, where users feel very cold during all the stay.

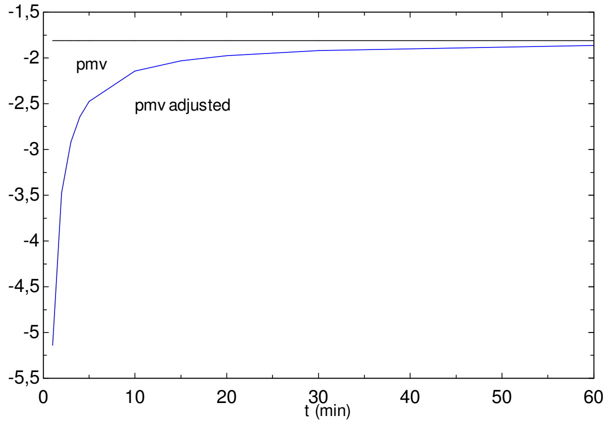

Figure 7: PMV and PMV adjusted inside of the trains

The situation is very uncomfortable. It is very difficult to solve the problems of transition in a space as complex as a metro station, but it seems reasonable to accommodate the set temperature of the air conditioning system inside the trains and to better ventilate the stations. Another possibility is, when feasible, to control the number of passengers entering at the same time into the station, with barriers or waiting spaces.

5. Discussion

In this work we have discussed the PMV theory and some changes that can improve it. Many methods have been developed to this effect, but normally these methods have not the physical basis of the Fanger's equations. The discussion over the acclimatization, started immediately after the publication of Fanger's book, showed that it is possible to enrich the method by adding new terms. So, for hot dry climates, the same Fanger proposed a correction to his equation.

The dynamic situations here studied, are an important part of the general phenomena called acclimatization. It is very common to refer at three different types of acclimatization: physiological, psychological and behavioral [4]. Under the time point of view, we can also refer to a long time acclimatization or to a short time acclimatization.

In this work, another term is introduced: the rapid change acclimatization. It is difficult to say which phenomena are present in the three different acclimatization times. It seems reasonable to assume the long time acclimatization to be both behavioral and physiological. Short time acclimatization (with the months of the year, for instance) can be probably more psychological. The newly introduced rapid acclimatization is clearly physiological, and it depends strongly on the metabolic processes of the body.

It has to be remarked that psychological effects can also be present. For example, people entering a very cold space, coming from a very hot environment, can vote expressing satisfaction. This it is not in contrast with the rapid change acclimatization. People feel, in reality, very cold, but this cold sensation is exactly what they desired. So, the psychological effect can be dominant over the physiological adaptation. This fact would not affect the importance of the transition evaluations.

The final form for the evaluation is proposed in equation (4):

$$\| S' \| = \| S \| - \frac{1}{n} \int \| S \| dt + \left\| \frac{\delta S}{\delta t} \right\| \Delta \qquad (4)$$

The integral term represents the long term acclimatization, the derivative term the rapid change effect. This equation has the form of a PID processor, and it seems a correct approach to the body response to environment. The coefficients of the correction terms will be obtained from field studies, which will start soon. The value of the coefficient n would be the number of integration steps, in a first approach.

In the future, a method of evaluation of this kind will probably be needed. To obtain this, it is important to describe very well the dynamic-mechanisms of our body. For example, it has to be expected the perception of cold discomfort to be faster than the perception of hot discomfort, because of the different number of regulation processes used to maintain the thermal neutrality: only one (vase constriction) in the case of cold and two (vase dilatation and sweat increase) in case of hot conditions. On the other hand, discomfort sensation due to hot conditions would be worse in the long term than cold discomfort sensation: initially, we can regulate skin temperature and energy losses associated to sweat, but we don't dispose of any metabolic regulation to eliminate the discomfort sensation created by wet clothes. Moreover, wet clothes can cause cold discomfort sensations, even once the environment becomes otherwise comfortable: it is hard to restore a good situation, not to mention unpleasant smells, ambient humidity increase due to sweat evaporation, etc…

So, the first need is to understand well the regulatory phenomena of the body, under critical dynamic conditions. Secondly, a general equation similar to the equation proposed here can be pursued. Finally, such an equation would, hopefully, become part of the architectural design process. Only with practice and experience we will be able to correctly use energy in order to realize the best comfort conditions for all the spaces we live in.

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