

Smart Control of Air Climatization System in Function on the Values of Mean Local Radiant Temperature

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The hygrothermal comfort indoor conditions are defined as: those environmental conditions in which an individual exposed, expresses a state of satisfaction. These conditions cannot always be achieved anywhere in an optimal way and economically; in some cases they can be obtained only in work environments specific areas. This could be explained because of air conditioning systems designing is generally performed both on the basis of the fundamental parameters' average values, such as temperature, velocity and relative humidity (T_a , v_a e ϕ_a) and derived parameters such as operating temperature and mean radiant one (T_{op} e T_{mr}). However, in some specific cases - large open-spaces or in case of radiating surfaces - the descriptors defining indoor comfort conditions, based on average values, do not provide the optimum values required during the air conditioning systems design phase. This is largely due to the variability of real environmental parameters values compared to the average ones taken as input in the calculation. The results obtained in previous scientific papers on the thermal comfort have been the driving element of this work. It offers a simple, original and clever way of thinking about the new domotic systems for air conditioning, based on the "local mean radiant temperature." This is a very important parameter when one wants to analyze comfort in environments characterized by the presence of radiating surfaces, as will be seen hereinafter. In order to take into account the effects of radiative exchanges in the open-space workplace, where any occupant may find themselves in different temperature and humidity conditions, this paper proposes an action on the domotic climate control, with ducts and vents air distribution placed in different zones.

Comparisons were performed between the parameters values representing the punctual thermal comfort, with the Predicted Mean Vote PMV, in an environment marked by radiating surfaces (i.e continuous glass) and calculated with the local radiant temperature suggested in previous works, with the corresponding values obtained always varying the air speed or the air temperature inflated from the air vents, in order to achieve the optimal comfort conditions.

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NOMENCLATURE

T_a = Air temperature, °C
 v_a = Air speed, m/s
 ϕ_a = Air relative humidity, dimensionless
 T_{op} = Operating temperature, °C
 T_{mr} = Mean radiant temperature, °C
 $T_{mr,l}$ = Local mean radiant temperature, °C
 T_j = Temperature of the j-th wall, °C
 $F_{i,j}$ = Factor of view of a j-th subject set at the i-the location of the environment, dimensionless
 S_j = j-th wall surface, m²
 f_{api} = Factor of projected area of the subject compared to the surfaces, dimensionless
 I_{clo} = Clothing thermal resistance, clo
 Met = Metabolic activity, Met

PMV = Predicted Mean Vote, dimensionless
 PPD = Percentage of dissatisfied, dimensionless
 PMV_m = Average Predicted Mean Vote, dimensionless
 a = Glass walls absorption coefficient, dimensionless
 I = Solar radiation incident on the glass surface, W/m²
 d_i = distance of the point of the environment, compared to the i-th wall, m

1. Introduction

From the beginning, man has always tried to create a thermal environment comfortable for his daily life, an environment able to guarantee him protection against the dangers represented by natural elements (wind, rain, humidity, cold or hot) as much as possible. At the beginning of the century, the idea of building air conditioning was still unknown; the only need was protecting themselves from the wind

and cold during the harsh winter seasons together with ventilating and humidify their house during summer months.

At the beginning of the last century there was the need of conditioning living and working environments through the use of installations capable of providing an heating thermal flow during the winter, and removing the amount of surplus heat during the summer period, with a system able only to heat or cool the air without guarantee the relative humidity control, in any way.

Only at the beginning of the '60 new air conditioning techniques developed in the US and later in Europe. They were obtained through the temperature and relative humidity control of air inside of living and working environments. From the 60's to the present many technologies to air conditioning in buildings have been developed. These are able to manage and monitor a wide range of meaningful thermal comfort parameters [1-16]. These technologies are now obtained with more sophisticated systems, in compliance with new regulations enacted (ISO7726 and ISO7730).

The condition of thermo-hygrometric comfort or well-being can be defined, from the psychological point of view, as the psychophysical state in which the subject expresses satisfaction with the thermal environment, or, from the thermo-sensory viewpoint, such as the condition in which the subject does not feel sensation nor of hot or cold (that is a neutral thermo-hygrometric condition), may having positive influence on our work efficiency.

In order to take into account the radiative exchanges effects in open-space workplace, where any occupant may be in different temperature and humidity conditions, this study proposes domotic intervention on the climate control system, using air ductings and air distribution vents within the various zones.

The type of installation proposed enables a locally action on the average parameters of the project -such as speed and air temperature- in order to allow individual occupants, exposed to radiative fluxes coming from the radiating surfaces, to obtain optimal comfort conditions locally, as it happens for example with air conditioning system for zones in cars.

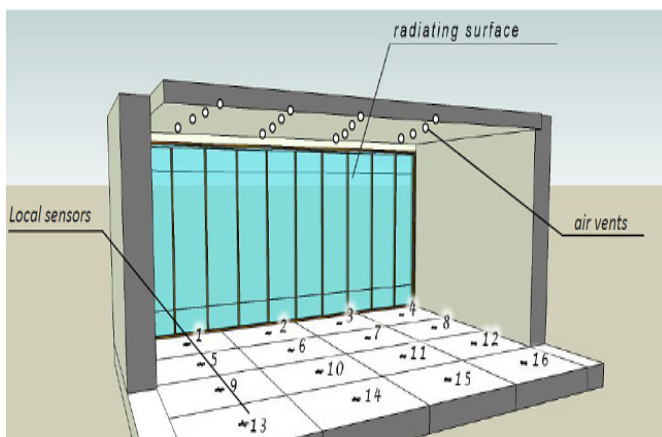


Fig. 1 Representation of the work open-space

The present study has been developed considering an open-space workplace (see Fig.1) marked by the presence of a continuous glass wall facing west, conditioned with an air system sent through air vents located at i points of the environment.

2. Calculation methodology

It known that the thermal comfort conditions inside an environment, depend on the values the basic parameters assume point by point. When you assume the average values of these parameters as inputs, you risk wrong interpretation of the local thermal situations [1-23].

In accordance with other articles on thermal comfort in open-space with large radiating surfaces [24-26], you can ensure that the radiant temperature in each point of the environment assumes different values in relation to the distance of the point from the radiating surface; consequently the average values used in the calculation programs produce Predicted Mean Vote, PMV values quite different from the average value calculated for the whole environment.

In this works, it became necessary suggesting a formula to calculate the local mean radiant temperature valid for the assessment of comfort based on the values of Predicted Mean Vote, PMV calculated in each point of the work environment.

This formula is as follows:

$$T_{mrl}^4 = \frac{\sum_{j=1}^6 F_{ij} \cdot T_j^4 \cdot S_j / d_i}{\sum_{j=1}^6 F_{ij} \cdot S_j / d_i} \quad (1)$$

with:

T_j = temperature of the j -th wall, °C

S_j = Surface j -th wall, m^2

F_{ij} = Factor of view of a the subject located at the point I of the environment, in relation of the j -th wall, dimensionless

d_i = Distance of the point of the environment, compared to the i -th wall, m

The values of the view factors F_{ij} can be calculated with the equation proposed by the same author [8-9] and adopted by ISO7726, [16].

3. Analysis of the results and considerations

In the simulations obtained during summer period for the study case, it has been assumed an open-space vented with air speed $v_a=0.15$ m/sec, occupied by persons performing activity of 1 Met in standing position, with clothing thermal resistance of 0.75 clo.

For the glass wall temperatures, it has been hypothesized temperatures $T_p=54, 60, 66, 70$ °C, typical of summer months in the Italian places.

The local mean radiant temperature values T_{mrl} , Predicted Mean Vote PMV and Percentage of dissatisfied, PPD have been calculated for each point of the open-space environment. Tables 1/a and 2/a show for the working environment i-th points the values of the average temperatures radiant local, T_{mrl} calculated with 1) and the corresponding values of the PMV and PPD associated with them for the respective cases already said.

Tables 1/b and 2/b show Predicted Mean Vote PMV and Percentage of dissatisfied PPD values obtained by keeping the same parameters of tables 1/a and 2/a, but varying only the air velocity value from the value $v_a=0,15$ to the one $v_a=0,25$ m/s.

Graphs of Fig. 2/a and 2/b have been constructed with the values reported in Tables 2/a and 2/b showing the PMV and PPD values as function of radiant temperatures for the two local air velocity assumed as $v_a=0.15$ m/s and $v_a=0.25$ m/s.

Average Predicted Mean, PMV_m and Average Percentage of dissatisfied, PPD_m values derived from project data are shown in the graphs below. and d), are shown in Figs. 2, 3, and 4.

Fig. 2/a and 2/b show that for air speed $v_a=0.15$ m/s measured in those points with local mean radiant temperatures (T_{mrl}) higher than 30°C , the PMV values are higher than PMV_m ones, while if the air speed is $v_a=0.25$ m/s, the values of the PMV are halved and they assume values very close to the optimal ones. higher than PMV_m ones, while if the air speed is $v_a=0.25$ m/s, the values of the PMV are halved and they assume values very close to the optimal ones.

The Fig.3 shows that the dashed curves represent the PMV_m values related to the two the air speeds. That confirms that small increasing of ventilation (passing from 0,15 m/s to the values 0,25 m/s) conditions improve significantly.

The same consideration can be deduced by observing the graph of Fig.3/b, where the percentage of dissatisfied PPD, between the two curves ($v_a=0.15$ m/s end $v_a=0.25$ m/s) decreased on average from 30% to about 10%, as we you move towards the most distant points from the radiating surface.

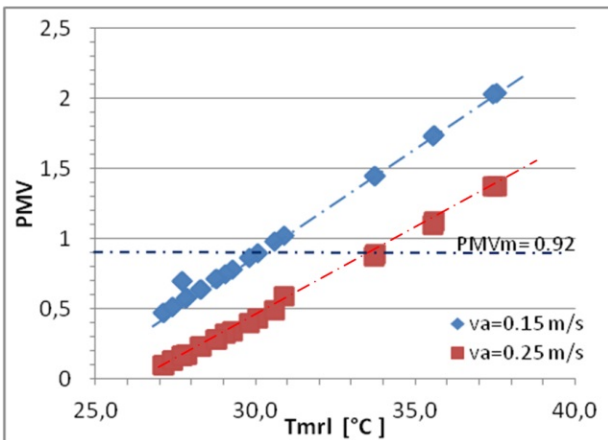


Fig. 2/a PMV of Table 2/a and 2/b in function of T_{mrl} , for $v_a=0.15$ and 0.25 m/s

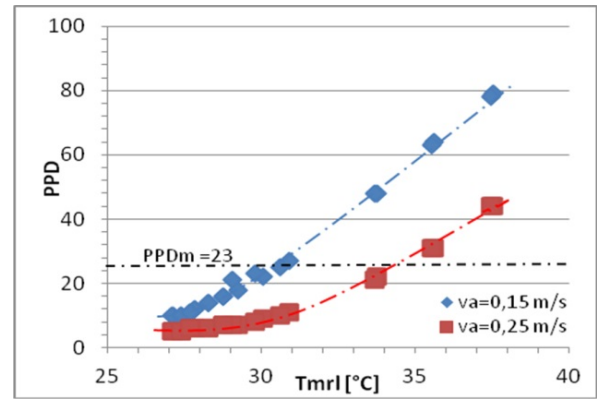


Fig. 2/b PPD of Table 2/a and 2/b in function of T_{mrl} , for $v_a=0.15$ and 0.25 m/s

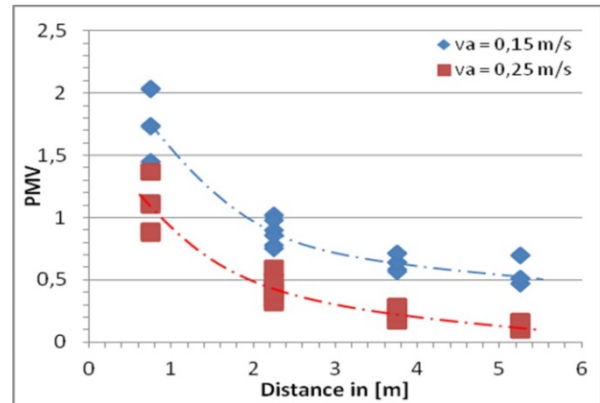


Fig. 3/a PMV of Table 2/a-b in function of radiating surface distance

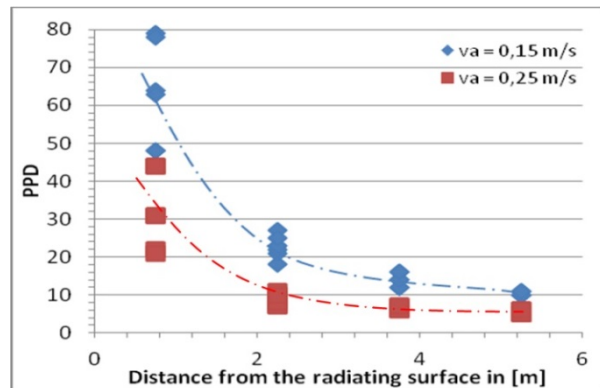


Fig. 3/b PPD of Table 2/a-b in function of radiating surface distance

Fig. 4 shows the color of Predicted Mean Vote PMV values deduced in the open space environment considered, obtained with the four possible settings:

- a) Air speed $v_a=0,15$ m/s e $T_a=26^\circ\text{C}$
- b) Air speed $v_a=0,25$ m/s e $T_a=26^\circ\text{C}$
- c) Air flow temperature $T_a=24^\circ\text{C}$ e $v_a=0,15$ m/s
- d) Air flow temperature $T_a=24^\circ\text{C}$ e $v_a=0,25$ m/s

The assessments performed through the four cases a), b), c) and d), are shown in Figs. 2, 3, and 4.

Table 1/a Air temperature values t_a , mean radiant temperature t_{mr} , PMV and PPD, standing persons $M=1.0$ Met, $I_{clo}=0,75$ clo, $v_a=0.15$ m/s, radiant surface $T_p=54-60-66^\circ\text{C}$

i- points		1 and 4	2 and 3	5 and 8	6 and 7	9 and 12	10 and 11	13 and 16	14 and 15
t_a		26,0	26,0	26,0	26,0	26,0	26,0	26,0	26,0
t_{mr}	$T_p = 54$	35,5	35,1	29,8	30,1	28,3	28,3	27,4	27,4
	$T_p = 60$	37,2	37,2	30,5	30,8	28,7	28,7	27,6	27,7
	$T_p = 66$	38,8	38,8	31,5	31,5	29,1	29,1	27,9	27,9
PMV	$T_p = 54$	1,73	1,74	0,86	0,90	0,64	0,64	0,51	0,51
	$T_p = 60$	1,99	1,99	0,96	1,01	0,70	0,70	0,54	0,55
	$T_p = 66$	2,24	2,24	1,11	1,11	0,76	0,76	0,58	0,58
PPD	$T_p = 54$	63	64	23	22	14	14	10	10
	$T_p = 60$	76	76	25	26	15	15	11	11
	$T_p = 66$	86	86	31	31	17	17	12	12

Table 1/b Air temperature values t_a , mean radiant temperature t_{mr} , PMV and PPD, standing persons $M=1.0$ Met, $I_{clo}=0,75$ clo, $v_a=0.25$ m/s, radiant surface $T_p=54-60-66^\circ\text{C}$

i- points		1 and 4	2 and 3	5 and 8	6 and 7	9 and 12	10 and 11	13 and 16	14 and 15
t_a		26,0	26,0	26,0	26,0	26,0	26,0	26,0	26,0
t_{mr}	$T_p = 54$	35,5	35,1	29,8	30,1	28,3	28,3	27,4	27,4
	$T_p = 60$	37,2	37,2	30,5	30,8	28,7	28,7	27,6	27,7
	$T_p = 66$	38,8	38,8	31,5	31,5	29,1	29,1	27,9	27,9
PMV	$T_p = 54$	1,10	1,05	0,40	0,43	0,23	0,23	0,13	0,13
	$T_p = 60$	1,33	1,33	0,48	0,52	0,27	0,27	0,15	0,15
	$T_p = 66$	1,54	1,54	0,60	0,60	0,32	0,32	0,18	0,18
PPD	$T_p = 54$	31	28	8	9	6	6	5	5
	$T_p = 60$	42	42	10	11	7	7	5	5
	$T_p = 66$	53	53	13	13	7	7	6	6

Table 2/a Air temperature values t_a , mean radiant temperature t_{mr} , PMV and PPD, standing persons $M=1.0$ Met, $I_{clo}=0,75$ clo, $v_a=0.15$ m/s, $a=0,6$ and $I=400, 500$ and 600 W/mq

i- points		1 and 4	2 and 3	5 and 8	6 and 7	9 and 12	10 and 11	13 and 16	14 and 15
t_a		26,0	26,0	26,0	26,0	26,0	26,0	26,0	26,0
t_{mr}	$I = 400$	33,7	33,8	29,1	29,3	27,8	27,8	27,1	27,1
	$I = 500$	35,5	35,6	29,8	30,1	28,3	28,3	27,4	27,4
	$I = 600$	37,5	37,5	30,6	30,9	28,8	28,8	27,7	27,7
PMV	$I = 400$	1,45	1,45	0,75	0,78	0,57	0,58	0,47	0,47
	$I = 500$	1,73	1,74	0,86	0,90	0,64	0,64	0,51	0,51
	$I = 600$	2,03	2,04	0,98	1,02	0,71	0,71	0,55	0,55
PPD	$I = 400$	48	48	21	18	12	12	10	10
	$I = 500$	63	64	23	22	14	14	10	10
	$I = 600$	78	79	25	27	16	16	11	11

Table 2/b Air temperature values t_a , mean radiant temperature t_{mr} , PMV and PPD, standing persons $M=1.0$ Met, $I_{clo}=0,75$ clo, $v_a=0.25$ m/s, $a=0,6$ and $I=400, 500$ and 600 W/mq

i- points		1 and 4	2 and 3	5 and 8	6 and 7	9 and 12	10 and 11	13 and 16	14 and 15
t_a		26,0	26,0	26,0	26,0	26,0	26,0	26,0	26,0
t_{mr}	$I = 400$	33,7	33,8	29,1	29,3	27,8	27,8	27,1	27,1
	$I = 500$	35,5	35,6	29,8	30,1	28,3	28,3	27,4	27,4
	$I = 600$	37,5	37,5	30,6	30,9	28,8	28,8	27,7	27,7
PMV	$I = 400$	0,87	0,89	0,32	0,34	0,17	0,17	0,10	0,10
	$I = 500$	1,10	1,12	0,40	0,43	0,23	0,23	0,13	0,13
	$I = 600$	1,37	1,37	0,49	0,59	0,28	0,28	0,16	0,16
PPD	$I = 400$	21	22	7	7	6	6	5	5
	$I = 500$	31	31	8	9	6	6	5	5
	$I = 600$	44	44	10	11	7	7	6	6

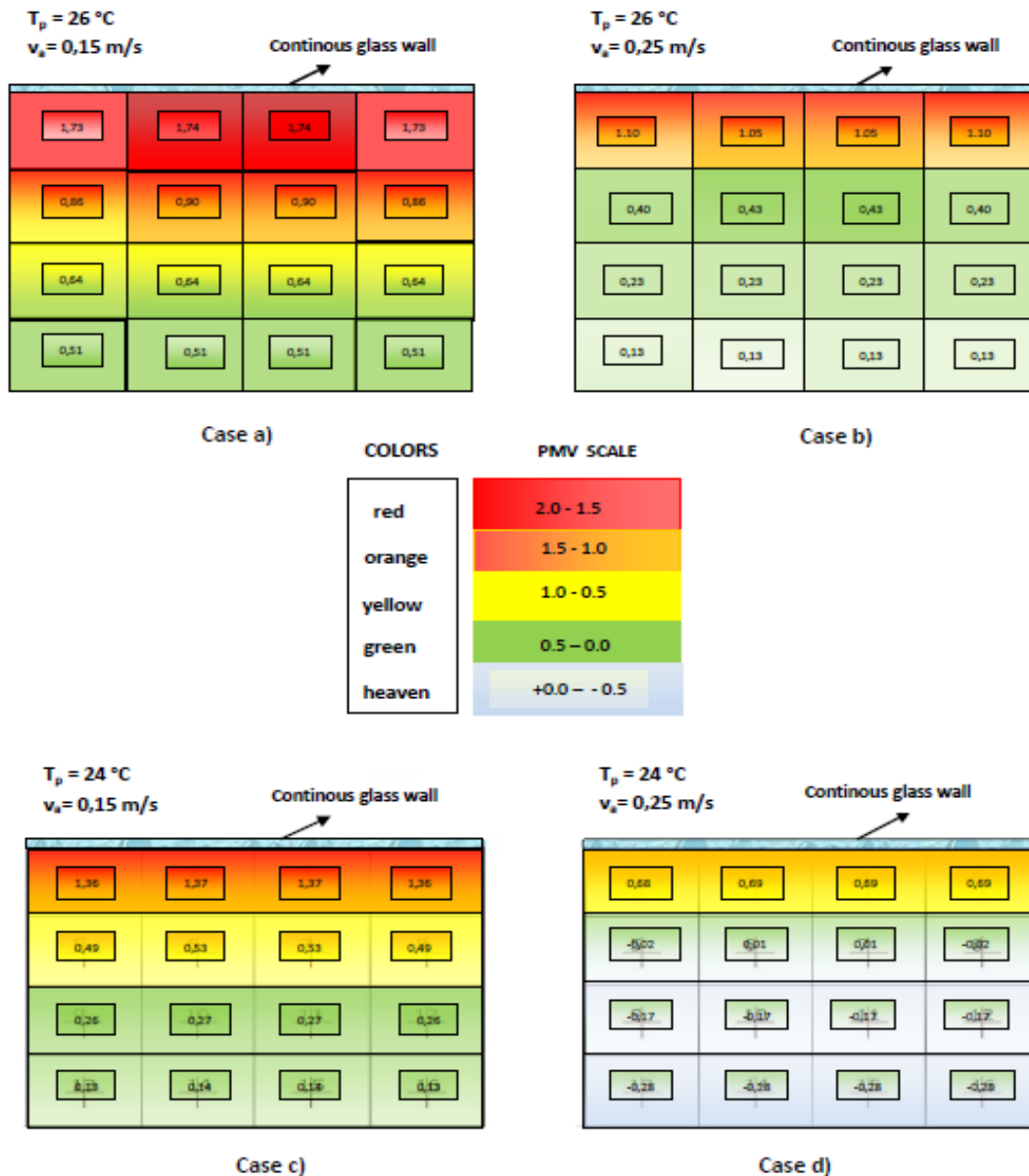


Fig. 4 Representation of the chromatic values of Predicted Mean Vote, PMV, within the work

4. Conclusion

In presence of radiation sources of great size or intensity, radiative exchanges greatly influence the local comfort conditions; therefore the average values are not representative of the real conditions of that specific point.

The domotic climate control intervention proposed in this paper is equipped with local radiant temperature wi-fi sensors, regulating the speed of the air vents along with a system that checks the flow temperature.

The proposed installation allows to obtain in every point of the open-space object of the study the best conditions required. The

evaluations carried out through the cases a) and b) and reported in Figs. 2, 3 and 4, show that a simple intervention on the speed of the air vents, allows you to get an intelligent control system, making it economical and versatile to the dynamic needs of the environment.

In those cases when the air velocity request exceeds the regulatory restrictions, it is recommended acting on the air flow temperature, adjusting this to some degree in order to obtain optimal local conditions.

(see tab.1/a and Tab.2/a, $I = 500\text{ W/m}^2$)

(see tab.1/b and Tab.2/b, $I = 500\text{ W/m}^2$)

Table 3 Scale of the values of the Predictor Mean Vote, PMV and Physical sensation

Predicted Mean Vote PMV	Physical sensation
+3	Very hot
+2	Hot
+1	Slightly hot
0	Neutral
-1	Slightly cold
-2	Cold
-3	Very cold

The adjustment of air outlet temperature from the vents is much more complicated than the single global speed one. In those cases illustrated in c) and d) - it could be more appropriate decreasing the air outlet temperature (from 26°C to 24°C) for a better management of the airflow system. If necessary, the air velocity from the vent can be changed from $v_a = 0.15$ m/s (case c) to $v_a = 0.25$ m/s (case d).

From visual observation of the four cases related to the possible adjustments of the system, you can notice that in case d) every point of the open-space environment shows optimal comfort conditions.

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