The applicability of the ISO 7730 (Fanger's comfort model) and the adaptive model of thermal comfort in Jakarta, Indonesia

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Abstract

A field study on thermal comfort has been carried out in the capital city of Jakarta, Indonesia. There were 596 office workers working in seven multi-storey office buildings participated in this study. Predicted neutral temperatures were read from thermal comfort meter type 1212, while the subjects' thermal sensations (the actual votes) were collected by means of questionnaire.

In view of thermal comfort knowledge there are still some arguments about the applicability of the thermal comfort standard ISO-7730, based on Fanger's comfort model, and the adaptive model of Humphreys, Nicol and Auliciems to be used in practice.

Results of this study shows there were only slight differences between the actual neutral temperatures (based on subjects' thermal vote) and both the predicted neutral temperatures measured by comfort meter (based on ISO-7730) and those calculated by Humphreys-Auliciems equations. The differences were statistically insignificant.

Key words : applicability, adaptive model, ISO-7730, neutral temperature, significant.

1. Introduction

Although the heat balance model is derived from a mathematical approach and seems fairly accurate to predict people thermal sensation, a number of comfort studies show some discrepancies between the actual and predicted thermal votes [1,2]. Using thermal comfort meter, the measurements of the PMV and PPD showed the values which are somewhat higher than the AMV (actual mean vote) and APD (actual percentage dissatisfied) [3]. This paper tries to assess whether there is a statistical difference between the 'actual' neutral temperature, ANT (based on subject's thermal vote), and the 'predicted' neutral temperature, PNT (based on ISO-7730 and the adaptive model of Humphreys, Nicol and Auliciems).

2. Method

A total of 596 office workers in seven office buildings namely, Agama (AG), BCA (BC), BPPT (BP), Dikbud (EC), LIPI (LI), Pajak (PA) and Widjojo (WI), participated in this study. The values of PNT were taken by using thermal comfort meter type 1212. Given any combination of clothing values and activities of the subject and being exposed to the environment where the subject takes a seat, the instrument will predict directly the temperature which is likely most suitable (comfort) for the subject. The instrument calculates the comfort (neutral) temperature is on the basis of Fanger's equation for thermal comfort. The ANT was calculated from a linear regression equation of subject's thermal sensation (based on the seven-point scale: -3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, +1 = slightly warm, +2 = warm, +3 = hot), against equivalent temperature. Subjects' thermal sensation were taken at the same time as the instrument was operated to predict the comfort (neutral) temperature. The calculation of the linear regressions were performed with Lotus 123 software for DOS, while the tests of significance for statistical analysis were computed by using Excel 4.0 software for Windows.

The measurement of temperatures in this study are expressed in three different terms, namely: air, operative and equivalent temperatures. The air temperature is the temperature of the air itself, the operative temperature is temperature which calculates the combination effect of air and radiant temperature from the surfaces, while the equivalent temperature is temperature which calculates the combination effect of operative temperature and air movement.

Since the comfort meter expresses the comfort temperature in terms of equivalent temperature, the comparison of ANT and PNT of ISO-7730 (Fanger's Model) is expressed in this unit of temperature. On the other hand, comparison between ANT and PNT of Adaptive Model are expressed in the difference terms of temperature i.e. air temperature since the adaptive model uses air temperature to express the neutral (comfort) temperature. Therefore, it can be seen that the values of ANT will appear differently in the two cases of comparison i.e. against ISO and the Adaptive Model.

3. Data and Results

3.1. Comparison with ISO (Fanger's Model)

The value of ANT and PNT in each building were derived from the 'average' values taken during the measurements in those buildings. Table 1 shows a comparison between the ANT and PNT in the seven observed buildings. The comparison was made in terms of equivalent temperature.

Table 1 : Comparison of neutral temperatures between actual and prediction based on ISO-7730 (Fanger's comfort model)

Building	**Number of subjects**	**Actual Neutral Temperature (°CT_{eq})**	**Predicted Neutral Temperature (ISO-7730) (°CT_{eq})**
AG	97	23.1	24.3
BC	103	25.9	25.1
BP	98	24.8	24.8
EC	96	25.1	24.9
LI	91	25.0	24.6
PA	41	26.3	24.7
WI	70	25.2	24.9
Mean		25.06	25.76
Variance		1.02	0.07

Table 2 : Test of significance between the ANT and the PNT based on ISO-7730

	t-test for means		**Significance**	**F-test for Variance**		**Significance**
Comparison between	t value	t-critical $\alpha=0.05$		F value	F-critical $\alpha=0.05$	
ANT and PNT of ISO	0.937587	2.446914	no	15.55396	4.283862	yes

Fanger's prediction seems not very bad, although the difference between the ANT and PNT in the two buildings, those are AG and PA were +1.2 and -1.6 respectively and these are quite large. The difference between the means of ANT and PNT was 0.7°C T_{eq}, while the difference between the variances was 0.95°C T_{eq}. The difference between the means was statistically insignificant, while the difference between variance was statistically significant. The significant difference of the variance seems due to the fact that the ANT were found differently in each building which could be a matter of subject's adaptation to their surrounding thermal environment.

3.2. Comparison of Results to the Adaptive Model of Humphreys, Nicol and Auliciems

Humphreys introduces the correlation between neutral temperature and outdoor temperature, which is different between naturally ventilated and air conditioned buildings [1]. With a coefficient correlation of 0.97, the equation for naturally ventilated buildings is :

$$T_{n1} = 11.9 + 0.534\ T_m$$

While for air conditioned buildings, with the coefficient of correlation of 0.56, the equation is:

$$T_{n2} = 23.9 + 0.295\ (T_m\text{-}22)\ \exp.\ (-((T_m\text{-}22)/(24V2))^2\ (°C)$$

On the other hand, Auliciems [4] re-analysed the regression data of Humphreys by deleting some of the input studies which used asymmetric scales of subjective warmth, those use children as subjects and those with monthly outdoor temperatures below -5°C, and replaced them with data from Australasian studies. By combining the naturally ventilated and air conditioned results together, he introduced an equation as:

$$T_{n3} = 0.48\ T_a + 0.14\ T_m + 9.22$$

where

T_{n1}	=	Predicted neutral temperature in buildings not using heating or cooling plant (naturally ventilated buildings)
T_{n2}	=	Predicted neutral temperature in buildings using heating or cooling plant (air conditioned buildings in the case of Jakarta)
T_{n3}	=	Auliciems' predicted neutral temperature
T_m	=	mean monthly outdoor temperature
T_a	=	mean indoor air temperature

To assess whether the adaptive equations of Humphreys and Auliciems are applicable for subjects in Jakarta, comparisons between ANT and the PNT which are calculated by using Humphreys and Auliciems equations are presented in Table 3. Humphreys' predictions are calculated by using equation (1) and (2) which are for naturally ventilated (NV) and air conditioned (AC) buildings, while Auliciems predictions are according to equation (3).

Humphreys and Auliciems predict that neutral temperature would be in the same direction as indoor temperature or mean outdoor temperature. The rise of indoor or outdoor temperatures will affect the higher neutral temperature of the subjects in the indicated environment. The comparison of ANT and PNT in this case uses 'air temperature' as an expression of the warmth. The values of ANT therefore appear differently to those in Table 1 in which the ANT were expressed in terms of equivalent temperature.

Table 3 : Comparison of neutral temperatures from the actual result and the predictions based on Humphreys and Auliciems methods

Building	Mean Monthly Outdoor Temperature (°C)	Mean Indoor Temperature (°C T_a)	Actual Neutral Temperature (°C T_a)	Humphreys' predictions (°C T_a)	Auliciems' predictions (°C T_a)
AG	28	30.3	25.8	26.9	27.7
BC	28	24.8	26.3	26.1	25.0
BP	28	27.8	26.0	26.1	26.5
EC	28	27.1	26.1	26.1	26.2
LI	28	27.0	26.7	26.1	26.1
PA	28	27.0	27.0	26.9	26.1
WI	28	24.4	25.6	26.1	24.9
Mean			**26.21**	**26.33**	**26.07**
Variance			**0.2248**	**0.1524**	**0.8957**

Table 4 : Test of significance between the ANT and PNT of Humphreys and Auliciems

	t-test for means		**Significance**	**F-test for Variance**		**Significance**
	t value	t-critical $\alpha=0.05$		F value	F-critical $\alpha=0.05$	
Actual and Humphreys	-0.55381	2.446914	no	1.60625	4.283862	no
Actual and Auliciems	0.348014	2.446914	no	3.659533	3.054552	yes

Table 5 : The deviation between ANT and PNT of Humphreys and Auliciems

Building	**Actual Neutral Temp.** (°C T_a)	**Difference predictions of Humphreys'** (°C T_a)	**Difference predictions of Auliciems'** (°C T_a)
AG	25.8	+1.1	+1.9
BC	26.3	-0.2	-1.3
BP	26.0	+0.1	+0.5
EC	26.1	0	+0.1
LI	26.7	-0.6	-0.6
PA	27.0	-0.1	-0.9
WI	25.6	+0.5	-0.7
Mean difference		**+0.11**	**-0.14**
Variance		**0.298095**	**1.179524**

Table 6 : Test of significance of the deviations of Humphreys and Auliciems

	t-test for means		**Significance**	**F-test for Variance**		**Significance**
	t value	t-critical $\alpha=0.05$		F value	F-critical $\alpha=0.05$	
Humphreys and Auliciems	0.873814	2.446914	no	3.956869	3.05455	yes

Based on equations (1) and (2), the PNT from Humphreys are found to be 26.9°C T_a for naturally ventilated buildings and 26.1°C T_a for air conditioned ones. While Auliciems predictions were between 24.9°C T_a and 27.7° C T_a.

Test of significance between the ANT and the Humphreys' PNT show that there were no statistically significant on both the mean and the variance (Table 4). However in the Auliciems' predictions, the difference between means was statistically insignificant while the difference between variances was statistically significant at 5% level (Table 4). Related to this study, the above tables shows that Humphreys equation is better than that of the Auliciems. Humphreys' equation predicts more precise both for the mean and for the individual case than that of the Auliciems. Table 6 shows the test of significance of the deviation from the actual neutral temperature between Humphreys and Auliciems' predictions. The difference of the deviation between the two predictions was significance in their variances, but not significant in their means. This indicates that on average they produce a similar prediction, but response differently in the individual cases.

The significant difference on variance found in Auliciems' case might be due to the neutral temperature equation introduced by him. Since Auliciems combined the equations for naturally ventilated and air conditioned buildings (from Humphreys' equations) to a single formula, he has eliminated the possible difference of subjects' attitude towards their surrounding thermal environments between those stayed in naturally ventilated and air conditioned buildings. In other words Auliciems reduced the magnitude of human adaptation towards their surrounding thermal environment. Thus, this can lead to a greater deviation between the prediction (based on his equation) and the actual result.

4. Conclusion

The predicted comfort temperatures both from ISO-7730 and the adaptive model showed only slight difference to the actual comfort temperature computed from subjects' thermal vote. The difference was statistically insignificant. Although there is a need for further investigation, results of thermal comfort study in Jakarta show that both the ISO and the adaptive approaches were somehow applicable to be used in a climate like Jakarta.

References

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