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Abstract. The home automation system to control the climatic health in confined environments is the subject of this article.
The standard UNI EN ISO 7730:2006 classifies the conditions of moderate confined environments by three categories according to the PMV index.
The comfort sensation is mainly affected by four variables: air temperature, mean radiant temperature, air velocity, relative humidity. They are all mechanical and thermal quantities therefore they are measured trough the same measurement method.
In evaluating the PMV index two more variables are taken into account: metabolism and clothing insulation. They can be evaluated by different accuracy levels. Their indirect measure is subjected to more uncertainty than the above four parameters measure and the distribution is typically non-Gaussian.
The paper analyses the uncertainty in PMV measuring trough the Monte Carlo simulation. The proposed study identifies the different weight of independent variables showing as their uncertainty, particularly the metabolism's and clothing insulation's one, affects considerably the final values for classifying the moderate environments.

Keywords. Home Automation, Thermal Comfort, Statistic analysis

1. Introduction

The prediction and measurement of temperature and humidity of thermohygrometric conditions of the occupants of a confined space are highly topical research fields.

Their importance lies primarily in the increasingly felt need to classify and possibly certify the comfort conditions in which the occupants, workers in particular, can work.

Infact the comfort condictions of the occupants greatly influence the productivity (Andersson et al., 2006).

Another aspect that is becoming increasingly important is the relationship between indoor comfort condictions and energy the buildings' consumption.

The latest European Directive on Energy Performance of Buildings, the 2010/31/EC, as art. 1, provides requirements on energy containment compared to the indoor environment.

Thinking in terms of mere energy savings alone without highlighting how the strategies to achieve it affect the living conditions inside buildings can be misleading (Corgnati et al., 2008).

The determination of the appropriate comfort conditions through specific indexes for the classification of indoor environments is the subject of the UNI EN 15251 (UNI, 2007).

Therefore there are two methods for calculating and the limit values depending on the type of buildings, subdividing between buildings equipped with heating and / or cooling and buildings without cooling systems.

In the first case the reference is to the UNI EN ISO 7730 (UNI, 2006), which was inspired from the Fanger's studies (Fanger, 1970) who proposed a method in which, through the measurement of 4 physical quantities related to the building envelope plus 2 subjective quantities depending from clothing and personal metabolism, it is possible to evaluate the quality of thermal comfort in a confined space.
The methodology was developed in the United States (primarily, in working places) and it is based on a statistical index called Predicted Mean Vote (PMV index), through a 7-point scale (Table I) in which a score is associated with the thermal sensation of the human body (UNI, 2006).

Although today the PMV index is the official method of reference, limited to the buildings above, its application has some difficulties (D'Ambrosio et al., 2008).

Table I – Point ASHRAE thermal sensation scale relative to PMV value.

Thermal sensation scale	
3	Hot
2	Warm
1	slighlywarm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

The comfort indexes depend on six variables, four are physical, and two are subjective. The four physical variables are: air temperature, mean radiant temperature, air velocity and relative humidity. These variables are related to the confined space.

The two subjective variables are: energy metabolism (M) related to physical activity, and thermal insulation (Icl) connected to the clothing worn.
The UNI EN ISO 7730 (UNI, 2006) includes explicit references in the evaluation of both the variables and the procedures through the UNI EN ISO 7726 (UNI, 2002), UNI EN ISO 8996 (UNI, 2005) and UNI EN ISO 9920 (UNI , 2009).

The first specifies the minimum required and desired characteristic of measuring instruments and referring to the measurement chain defines metrological parameters, including range and maximum permissible uncertainty, referred to in paragraph 2.

Some commercially available certified systems of measurement, mostly for professional use, with the requirements of the UNI standard (7730) and, the authors make reference to these tools.

It has been suggested that the metrological parameters related to the UNI EN ISO 7726 (UNI, 2002) such as field and uncertainty about the nature of physical measurements always have a Gaussian distribution.

About UNI EN ISO 7726 (UNI, 2002) it can be seen that it requires the mean radiant temperature an accuracy of ± 2 ° C

Some authors (D'Ambrosio et al., 2011) show that being this one an indirect measure, whose independent variables are: air temperature, air velocity and temperature of the globe thermometer, the uncertainty will be certainly function of the latter and the value of the required accuracy is difficult to achieve.

However, for the purposes of this work we don't take account of this aspect.

The UNI EN ISO 8996 (UNI, 2005) takes into account the evaluation and measurement of human metabolism. It offers (iouserei recommends al posto di offers) four levels of evaluation (1-Screening, 2-Observation, 3-Analysis, and 4-for Experts) which can be divided into one or more methods.

Level 4 provides for the assessment of energy metabolism based on measurement of various biometric data. In this method the rule associates a value of uncertainty next to ± 5%.

The operating limits of this procedure, however, are given from the complexity of the operations of the direct measurements on the human body and the UNI EN ISO 7730 (UNI, 2006) suggests to use the level 1 table to which the UNI EN ISO 8996 (UNI, 2005) associates uncertainty values approaching 20%.

Olesen and others (Olesen et al., 2002) indicate a value for the same level of uncertainty of ± 15%.

The UNI EN ISO 9920 (UNI, 2009) shows how to evaluate the thermal resistance of clothing through direct and indirect measures.

The standard takes into account the effect of thermophysical parameters such as wind speed and physical activity exerted by the body.

In case of direct measurement an appropriately instrumented manikin is positioned inside a climatic chamber.

Measurements with accuracies of between 5 and 10% are obtained. In case of indirect measurement type of clothing is evaluated differentiating by gender (male / female) and season (summer / winter).

The thermal insulation value is a function of the combination of garments worn or is classified according to the type (work, daily, etc. ..).

The UNI standard *(9920)* does not explicitly define the associated uncertainty, but generally speaks of valuation - "Estimation of thermal insulation and water vapor resistance of a clothing ensemble" - and not of the measure.

If you would like to proceed with the direct measurement of Iclyou should take into account of the errors using the method of propagation of uncertainties. At the operational level it would be possible to assess the order of magnitude of the error through the significant figures given in the tabulated values as rules governing the SI. Olesen and others (Olesen et al., 2002) associated with this evaluation an uncertainty of ± 15%.

Which final uncertainty should be expected in the case of a correct application of EN ISO 7730 (UNI, 2006) and implementation of the 4 measures of the variables for the calculation of PMV, is the subject of this study.

As other authors highlight, (D'Ambrosio et al., 2011), the uncertainty associated with the average value of one or more variables could easily slide the PMV value within categories of thermal environment (A, B, C) contiguous (UNI , 2006, 2007) summarized in Table II.

Tabella II - Classificazione proposta dalle norme UNI 7730 ed UNI 15251

Category		Thermal state of the body as a whole
UNI 7730	UNI 15251	
A	I	-0,20 < PMV < 0,20
B	II	-0,50 < PMV < 0,50
C	III	-0,70 < PMV < 0,70
-	IV	PMV < -0,70 o PMV > 0,70

The correct evaluation of the two subjective variables accentuates this account for another aspect related to the different distribution of typical tabular data which by their nature express the physical phenomenon in a discrete and not continuous way.

In this case, since the UNI EN ISO 7730 (UNI, 2006) provides for the allocation table of the values of M and Icl, described above and their uncertainty is similar to a rectangular distribution.

The tabular values do not converge around the mean as in case of a direct repeated measurement, but for the entire interval of uncertainty we have the same level of probability of being able to find the value of the variable.

Therefore, the dependent variable PMV will be affected by the uncertainties propagated related to the nature and to the estimation procedures of the six independent variables.

The purpose of this paper is to evaluate the uncertainties in the calculation of the PMV from the uncertainties of all six variables that contribute to its definition.

For this purpose the Monte Carlo simulation is used (UNI, 2000). Special conditions suggest the use of this method.

First, the distribution of uncertainty of the six variables is not constant, and it can be considered as Gaussian for the physical ones and rectangular for the subjective ones.

This consideration suggests that the application of the method of propagation of uncertainties couldn't be exhaustive in this task.

The UNI 13005 (UNI, 2000) considers the same Monte Carlo simulation as a method to validate the results obtained from the law of propagation of uncertainty.

Furthermore, as shown in the UNI EN ISO 7730 (UNI, 2006), the analytical procedure of calculation involves the resolution of a non-linear system of four equations.

The Monte Carlo method allows to evaluate by computer methods the uncertainty associated with the distribution of the variable PMV, streamlining the complexity of typical analytical calculation of the law of propagation of uncertainty.

2. The Monte Carlo simulation

The UNI 13005 (UNI, 2000) provides two methods for the evaluation of uncertainties for indirect measures. The method of propagation of uncertainty and the Monte Carlo method. The two methods differ in both the data input and output.

In the method of propagation of the uncertainties of the input data are represented by the measures in the form: mean value (Mx) and standard deviation (SMX) and outgoing MMM we will have a mean value and standard deviation of the function sought SMM

As forecasting model for the evaluation of the uncertainties, the Monte Carlo simulation, in the case in which the frequency distribution of the input variables is of a different nature.

The application in question is based on the numerical method proposed by UNI 13005 (UNI, 2000) and has as output variable the mean value of the PMV.

The method allows to obtain the measurement of uncertainty and all of the data to define the function of probability distribution.

The goal is to determine the range of coverage with the degree of approximation of 95%.

This degree of accuracy is a measure of model fidelity and of the information quality that has the probability density function for the independent variables in the model.

The UNI 13005 (UNI, 2000) proposes two methods: the "Adaptive Monte Carlo procedures" or the "full method".

The first has so far been preferred as more efficient from the point of view of the use of software and hardware resources, although it is more laborious from the point of view of programming.

Modern information technology allows, however, to apply the "full method" without time machine too long.

For the application in question therefore was preferred the latter.

The operational approach provides that each value of the input variables is random and that it is defined as the probability density function, and this approach is also known as propagation of distributions.

Regardless of the type of input distribution, the probability density function of the output will be unique, as shown schematically in Figure 1.

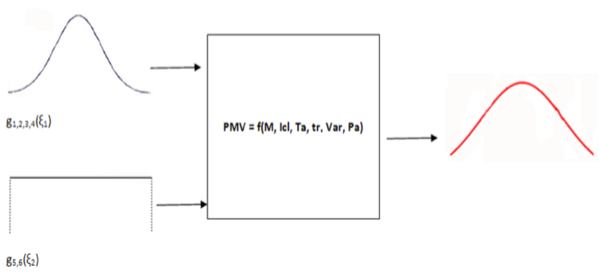


Figure 1 - Distribution of probability of PMV in function of the probability distribution of the input variables

In the application in question the input variables are the four physical environment related to confined location and the two subjective linked to the occupants, while the output variable is the index PMV (Figure 2).

Once the probability density function for the output variable, if the PMV, is known, its value is taken as the most probable estimate of the final value and its uncertainty is assumed to be equal to the standard deviation. In this way you get a coverage factor for the variable rate of 95%.

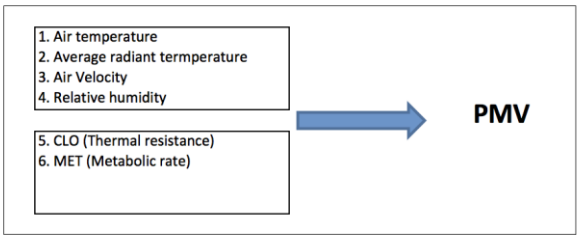


Figure 2 - Variables in the input and output of the Monte Carlo method

Table III shows the average value of the input variables

Table III: Value of input variables for the application of the Monte Carlo simulation

The instrumental accuracy required by the UNI EN ISO 7726 (UNI, 2002) was taken as the uncertainty of the physical variables.

For the uncertainties associated with the variables M and Icl, reference was made to Olesen and others (Olesent et al., 2002) and therefore assumed an uncertainty associated with the mean value equal to 15% with rectangular distribution.

The model established by UNI 13005 (UNI, 2000) is expressed by the functional relation (1):

PMV = f(M, Icl, ta, tr, Va, RH), (1)

Microclimatic and subjective variables investigated values

Parameter	Symbol (units)	average value
Metabolic rate	M (W/m^2)	69,78
Static clothing insulation	Icl (m^2K/W)	0,155
Air humidity	R.H. (%)	40
Average radiant temperature	tr (°C)	18
Air temperature	ta (°C)	19
Absolute air velocity	Va (m/s)	0,1

where the symbol is the same the table 3

M is the metabolic energy;

Icl is the thermal insulation of clothing;

ta is the air temperature;

tr is the average radiant temperature;

var is the air relative velocity;

pa is the partial vapour pressure of water;

The six input variables propagate the probability density function gi (ξi), i = 1,. . . , 6.

The values of the used model, corresponding to the set of input values in Table 3 contribute with different weights, given by equation (1), to the output value of PMV.

The model that generates the probability density function for the PMV is described graphically in Figure 1.

The four probability functions of the physical parameters g1, 2,3,4 (ξ1) ξ1 are related to the Gaussian distribution, while the functions g5, 6 (ξ2) of the subjective parameters are processed as probability density rectangular (ξ2).

The values of the uncertainties and the distribution function of the individual input variables is represented in Table IV

Table IV: Metrological characteristics of the input variables

Microclimate and subjective variables with uncertainty and corresponding distribution

Parameter	Symbols (units)	Uncertainty	Distribution
Metabolic rate	M (W/m^2)	±15%	rectangular
Static clothing insulation	Icl (m^2K/W)	±15%	rectangular
Vapour partial pressure	Pa (Pa)	0,15kPa	Gaussian
Average radiant temperature	tr (°C)	2°C	Gaussian
Air temperature	ta (°C)	0,5°C	Gaussian
Absolute air velocity	Va (m/s)	),05+0,05Va) m/s	Gaussian

The Monte Carlo simulation through the numerical method, approximates the distribution function G (η) through the value of the output quantity of the function of the PMV.

Through a personal computer constituted as shown in Table 5 it was generated a sample of random values input such as to have a high number $N = 10^6$ for the PMV.
The input data of the model were included according to the model D'Ambrosio et al., 2008 in which it tr = ta.
The value of the associated uncertainty is that of tr (the greater of them).
The standard deviation of the magnitudes with the rectangular distribution were evaluated as UNI CEI ENV 13005
The value of Va was varied not over the entire range of uncertainty, but only with respect to the positive values.
This is because the value stated for the accuracy of the measurement, if the average value is small, close to 0.1 m / s, these values generate an error in the simulation system due to negative values of the speed that would be generated.

Table V: Features of the computer used for the simulation

Personal Computer	
components	**features**
CPU	core 2 quad CPU Q8300 2,50 GHz
RAM	6 GB
OS	64 bit
Software	64 bit

The PMV was calculated for each 6-variables sequence through a program based on Appendix D of the UNI EN ISO 7730 (UNI, 2006). The accuracy in the implementation has been checked through a classic bottom-up test.

Through a recursive procedure depending on the type of implementation were analysed and programmed the type of data to be generated, its range of validity and its resolution metrology according to Table 4.

the mean and the standard deviation were calculated and verified that each variable was coherent with the expected results. As example Figure 3 shows the variable air temperature represented graphically through its cumulative distribution function of frequency.

Of the same variable it is shown its probability distribution (Figure 4) that serves as a graphical model to be compared with the probability distribution of the values of PMV in red.

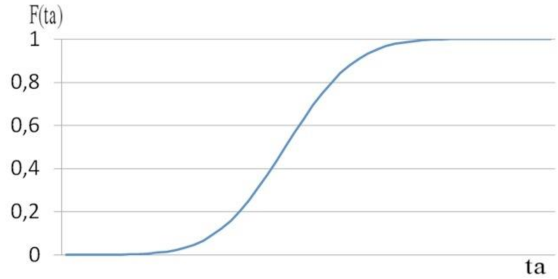


Figure 3 - Cumulative frequency of the standardized variable **ta**

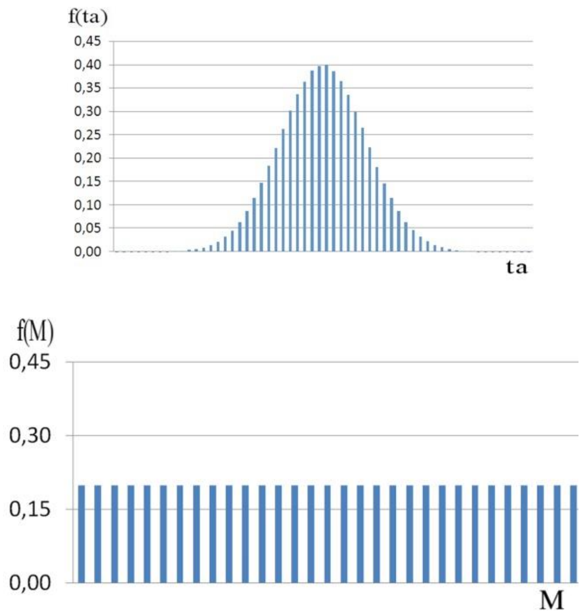


Figure 4 - Frequency distribution of standardized variables at the left and right M

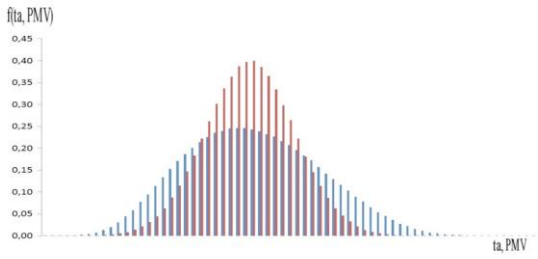
3. Results

Due to the presence of rectangular distributions as input the mean value of the PMV does not coincide with the expected value (-0.7).

It is obtained a value dependent on the resulting distribution that tends to shift the mean value in function of the value of kurtosis. Table VI, shows the main results.
As significant index of central tendency and dispersion of the value of PMV is reported the value of the parameter kurtosis (-0.424) which denotes numerically and graphically (Figure 5) the classic trend platicurtico (index of negative kurtosis).

The result obtained further confirms the results presented by D'Ambrosio (D'Ambrosio Alfano FR, et all. 2011); through the index of kurtosis displayed graphically by the performance of Figure 5, this one is more emphasized in the comparison chart of Figure 5.
It was not easy to predict in a system of equations such as that proposed in the UNI EN ISO 7730 (UNI, 2006) and may also be interesting because it shifts the index of central tendency from "normality" of the Gaussian curve giving more importance to the tails and then further confirming the liability of the measures and further increasing the consideration of "randomness" in the assessment of the value of PMV.

Table VI: Results obtained from Monte Carlo simulation



PMV: Simulation results	
N input variables	6
N sample	10^6
Distribution	gaussian and rectangular
Average value	-0,471
Standard deviation	0,18
Kurtosis index	-0,424

Figure 5 – Graphic comparison between the distributions of the variables **ta** in red and in blue color PMV

4. Conclusions

The Monte Carlo simulation has proved to be effective and appropriate to the complexity of the system of four equations in which one has as a method of solving a recursive procedure.

is usable for the calculation of the PMV value with all its six input variables.

Once implemented the method is easily associated with a user interface that facilitates the introduction of the input data to test making the automatic method.

Compared with the method of propagation of uncertainties can be obtained in addition to the uncertainty associated with the given mean value, although the frequency distribution of the output variable of the method by providing greater "sensitivity" to the control system in home automation.
The proposed case the calculation of the PMV check the reliability of the Monte Carlo simulation as a tool for control of the results obtained through the law of propagation of uncertainty.

5. Aknowledgements

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