A COMFORT FIELD STUDY IN PUBLIC TRANSPORTATION BUSES

C. J. O. P. J. Alcobia and M. C. G. Silva

DEM – FCT, Universidade de Coimbra – Pólo II
3030 Coimbra, PORTUGAL

ABSTRACT

The initial findings of a project initiated in the University of Coimbra and dealing with the conjugated influence of multiple stressors in riding passengers are presented in this paper. A field study in public transportation buses was conducted, having been the subjective responses of the occupants collected and the physical parameters related to the thermal comfort, noise, vibration and air quality acquired.

In the questionnaires, the PMV scale was used to evaluate the thermal aspects and, for the other stressors, a five-point scale, from very uncomfortable to very comfortable, was used. The results of the statistic treatment of data, including the correlations between the indices resulting from the measured physical parameters and the subjective responses are presented.

Even if it looks too far, the final goal of the project is to obtain a general comfort index that takes into account the influence of multiple stressors.

KEYWORDS

Case Studies, Comfort, Thermal comfort, Air quality.

INTRODUCTION

The mobility exigencies of the daily life imply that people spend an important part of their time inside transportation means. The society development contributed to increase the attention given to the conditions inside vehicles, where different factors can act as discomfort stressors, namely thermal aspects, ergonomics, vibration, air quality and light.

Many studies were carried out to evaluate the comfort conditions in vehicles; most of them in the field of one of the stressors formerly mentioned, and less considering multiple influences. So, the available scientific data gives little information about the discomfort due to different causes acting at the same time. Griffin (1995) launched the idea of a model capable of considering the influence of multiple sources in the comfort evaluation of vehicles, identifying the possible causes of annoyance and defining the way to create a weighted index. The effects of simultaneous noise and vibration on the subjective responses of persons occupying buildings close to railways are reported by Howard and Griffin (1990).

Clausen *et al* (1993) studied the relative importance of sensory air pollution, thermal load and noise under controlled conditions in two climatic chambers. Former experiments, where the conjugated effects of thermal load and noise were studied are also reported by those authors, starting in the very first research from Viteles and Smith (1946).

Yamazaki and co-workers studied the multiple influence of temperature, light and sound on the perceived work environment (Yamazaki *et al* (1998)), presenting a general work suitability index.

METHODS

The subjective response of the occupants and the time evolution of the physical parameters used to characterise the environmental comfort of people were collected during four test campaigns, that took place throughout travels of urban buses in the city of Coimbra.

A one-sheet questionnaire was used to pick up the informations about and the votes from the inquired passengers. As the permanence time of a passenger in an urban public transportation bus can be short, in the questionnaire elaboration, it was assumed that to fill it no more than 2-3 minutes should be taken. In order to improve the speed of the process, three persons acted as inquirers, fulfilling themselves the questionnaires with the occupants responses. The questionnaire has seven data fields, being the first one dedicated to the demographic characterisation of the inquired person; the second to the filling occasion time (YY:MM:DD - HH:MM) and the remaining five to the votes about thermal comfort, air quality, noise, vibration and global comfort. With the exception of the thermal comfort, in which case the seven points PMV scale was used, the voters were asked to express their feeling in a five point scale, defined from very uncomfortable (-2) to very comfortable (2).

In what concerns the measurement of physical parameters the following equipment was used:

Thermal comfort – a Brüel & Kjaer type 1213 Indoor Climate Analyzer (ICA), with five transducers for air velocity, air temperature, humidity, radiant temperature and operative temperature. The data logger capabilities of the ICA were used to store the values every 6 minutes. After each test the data file was transferred to a PC laptop computer.

Noise – a Brüel & Kjaer Noise Dosemeter type 4436. The Leq values, curve A weighted, based on an integration time of 1 minute where acquired by the dosemeter and later transferred to a computer through the RS232 serial port.

Vibration – the primary sensor was a Triaxial Seat Accelerometer Type 4322, from Brüel & Kjaer. It was connected to a Sound Level Meter Type 2231 through a Human Vibration Unit type 2522. The Sound Meter was charged with the software from the Human Vibration Module BZ 7105. The equivalent acceleration a_{eq} (m/s^2), in the three orthogonal axes, weighted according to ISO Standard 2631(1985), was acquired each two minutes.

Air Quality – an electrochemical Indoor Odour Sensor, with the reference NAP-11AS and supplied by RS Components, was used to monitor the air quality inside the passenger compartment. A data logger, configured with 1 minute throughput, was used to save the data.

Two seats in a mid position, just after the central platform used by standing passengers, were used to install the measuring and data acquisition equipment.

The ventilation system of the bus is assured by small tilting openings in the upper part of bus windows and by the windscreen glass defrosting openings. The side windows remained closed during the tests, because the passengers didn't open them.

RESULTS

The summer tests took place in the 26th of June and 11th of July of 1997. The chosen days didn't revealed quite meaningful in what concerns the typical Portuguese summer weather, because the sky was cloudy and the maximum outdoor temperature didn't exceed 26° C.

In the other way, the days elected for winter tests, the 12th and 26th of February of 1998, were very warm for the season, with sunny weather and mild outdoor temperatures.

The operative temperature evolution

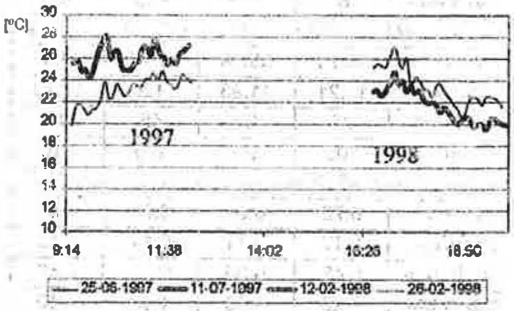

Figure 1 – Operative temperature evolution during the four tests.

registered during the four tests, inside the bus passenger compartment is depicted in the figure 1. The first set of tests (1997) took place during the morning, while the second one (1998) occurred during the afternoon.

All the tests lasted more or less 3 hours, which was the period necessary for the completion of 3 tours of the bus in the respective line. Two different bus lines were used. In the first set of tests (summer 1997), the line was more irregular, with pronounced slopes and tracks in urban and suburban areas, thus resulting in quite non-uniform conditions for the bus velocity and engine rotation. The line used in the second set of tests (winter 1998) was completely urban, which implied a much more constant bus velocity, imposed by the city traffic restrictions.

The summary of the demographic characteristics of the inquired populations is depicted in table 1.

Table 1
Statistical Summary of Occupants

	25-06-97	11-07-97	12-02-98	26-02-98
Sample Size	68	72	61	55
Gender				
male	31	33	17	19
female	37	39	44	36
Age (years)				
mean	35.68	39.29	30.64	32.56
std. dev.	18.56	20.4	14.43	16.31
minimum	10	12	13	16
maximum	76	79	67	80
Height (cm)				
mean	163.51	164.31	164.52	164.36
std. dev.	9.86	9.46	9.11	10.27
minimum	130	139	143	140
maximum	185	187	190	190
Weight (Kg)				
mean	62.78	65.89	62.46	63.85
std. dev.	14.21	11.93	11.25	12.53
minimum	35	30	45	42
maximum	105	95	105	110
CLO				
mean	0.72	0.57	0.80	0.80
std. dev.	0.17	0.11	0.14	0.15
minimum	0.48	0.35	0.35	0.50
maximum	1.20	0.83	1.10	1.10

Some differences were detected in the demographic characteristics of the attendants of the two lines, corresponding to a younger sample, with a stronger feminine predominance in the second line.

Table 2
Summary of Physical Measurements

	25-06-97	11-07-97	12-02-98	26-02-98
Th. Comf. PMV				
mean	-0.7	-0.2	-0.8	-0.3
std. dev.	0.3	0.4	0.4	0.4
minimum	-1.4	-0.8	-1.4	-1.0
maximum	-0.1	0.6	0.0	0.7
Air Quality [Volt]				
mean	7.91	8.15	7.98	8.00
std. dev.	0.30	0.23	0.16	0.14
minimum	7.04	7.75	7.53	7.73
maximum	8.23	8.65	8.28	8.26
Noise Leq (dB(A))				
mean	73.2	75.7	73.1	72.7
std. dev.	2.4	3.6	2.0	2.6
minimum	67.3	66.5	68.2	66.1
maximum	79.5	83.5	78.6	77.1
Vibration Sum [illegible]				
mean	0.38	0.37	0.31	0.33
std. dev.	0.17	0.16	0.08	0.09
minimum	0.00	0.06	0.12	0.12
maximum	0.91	0.86	0.50	0.69

Table 3
Summary of Subjective Votes

	25-06-97	11-07-97	12-02-98	26-02-98
Thermal C.				
mean	0.21	0.56	0.41	0.45
std. dev	0.61	0.74	0.61	0.87
Air Quality				
mean	0.07	0.22	-0.07	-0.16
std. dev	0.69	0.69	0.51	0.62
Noise				
mean	-0.12	-0.06	-0.42	-0.43
std. dev	0.78	0.81	0.56	0.68
Vibration				
mean	0.09	0.24	-0.15	-0.25
std. dev	0.85	0.74	0.57	0.74
Global C.				
mean	0.37	0.58	0.10	0.09
std. dev	0.71	0.57	0.69	0.79

Statistical summaries of the physical measurements and subjective votes are presented in Table 2 and Table 3, respectively.

For the air quality, the voltage output of the electrochemical sensor is used, because there were no means to calibrate its response in other more adequate units (decipol).

The physical assessment of the vibration level inside the bus is done using the three axis weighted acceleration, the Sum [m/s^2] quantity:

$$\text{Sum} = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z},$$

where a_x, a_y and a_z represent the root mean square of the acceleration signal, in the respective axis, frequency weighted according to ISO 2231.

The formerly mentioned fact that the outdoor weather conditions were not very different during the four days is confirmed by the observed mean clothing values (cf. Table 1). Nevertheless, it can be seen that the second test occurred in a warmer day than the others did.

From the analysis of Table 3, noise was considered by people as the main cause of discomfort, because it is the only one cause always being negative and with larger absolute values than others. However, in the second test, if the scales were adimensionalized, the discomfort due to the thermal environment (warm side) would be higher than the one resulting from noise.

Some influences of the sociological differences between the populations inquired in the first two and last two tests are also detectable in the subjective assessment data. The declared annoyance is larger in the last two tests, where the population sample was younger and more urban. No valid reason for this discrepancy can be found in the physical records. For instances, the noise level registered during the first, third and fourth test was almost the same (cf. Table 2), and in the second test, the one receiving the less annoyance vote (-0.06), was even 3 dB(A) higher. A similar behaviour is detectable with the other discomfort factors.

Table 3, about the subjective assessment, is completed with the voting histograms presented from figure 2 to figure 6. Four different bars, placed by chronological order, are used in each vote, to represent the data of the four tests.

Passengers judged the thermal environment mainly as neutral or slightly warm, with the votes in the extreme points of scale almost without significance.

The air quality was the factor with a lower percentage of dissatisfied about it. The aforementioned fact about the less tolerant population in tests three and four is also verified.

As already stated, noise was the main annoyance cause, with percentages of dissatisfied between 25% (1st test) and 45% (3rd test). Nevertheless, the registered L_{eq} average values would suggest an even worth voting, according to Clause et al (1993) results. For a L_{eq} value around 70 dB(A), the percentage of dissatisfied reported by those authors is 90%. A probable reason for the difference is the fact that, in a bus, noise is more tolerated because is less "unexpected" than in a climatic chamber pretending to simulate a house ambience.

The measured vibration levels in the first and second test (0.38, 0.37), according to ISO Standard 2631 (1997), correspond to a little uncomfortable situation, while the third and fourth tests (0.31, 0.33) are exactly in the border between not uncomfortable and a little uncomfortable. The vibration subjective assessments confirm the previous classifications, all them with an absolute value lower than 0.25.

The judgement about the overall comfort inside the buses was slightly positive, meaning that most of people considered the situation as neutral.

From figure 7 to figure 10, the time evolution of the comfort indices used to evaluate each stimulus are presented in conjunction with the moment votes of passengers. All the data refers to the 11/07/97 test, used here as example.

In what concerns the thermal comfort, the subjective votes are typically one unit over the measured PMV values. The tendency line, computed from the subjective data using the smooth centered

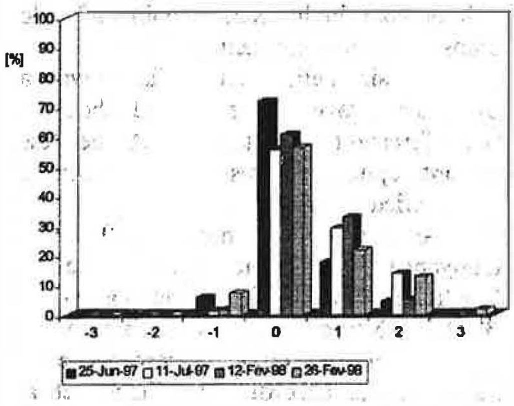

Figure 2 – Histogram of subjective assessments about Thermal Comfort

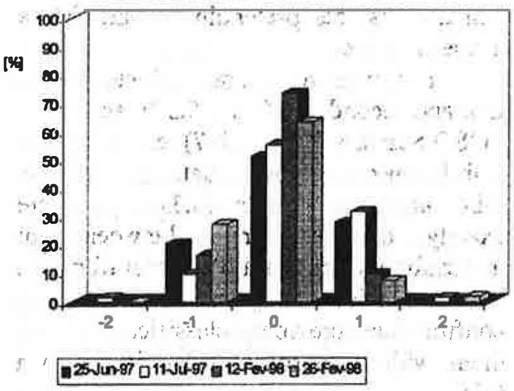

Figure 3 – Histogram of subjective assessments about Air Quality

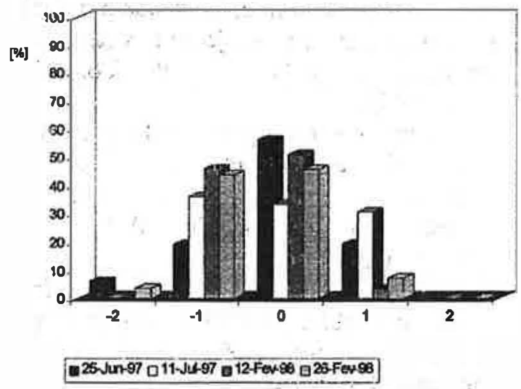

Figure 4 – Histogram of subjective assessments about Noise

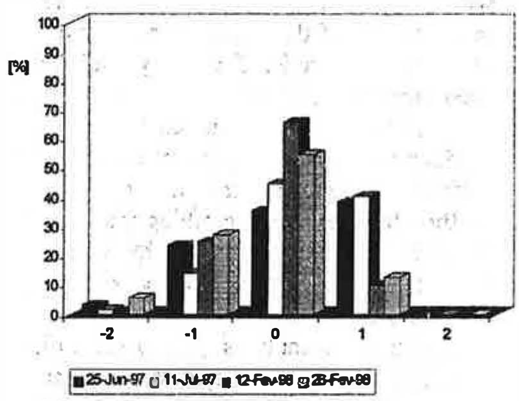

Figure 5 – Histogram of subjective assessments about Vibration

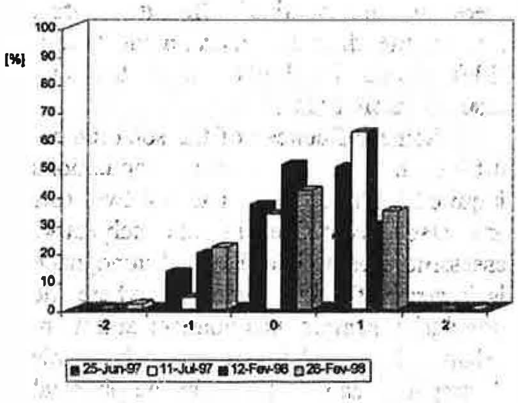

Figure 6 – Histogram of subjective assessments about Global Comfort

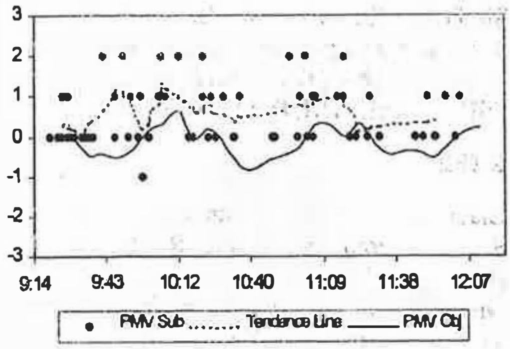

Figure 7 – Time evolution of PMV and subjective votes about Thermal Comfort

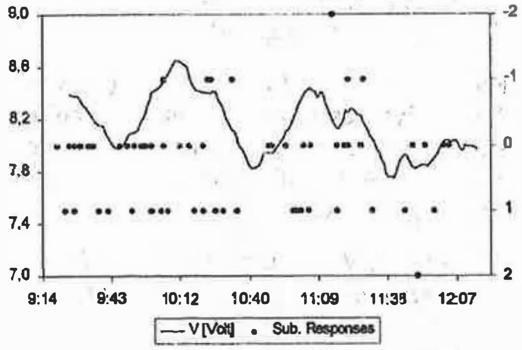

Figure 8 – Time evolution of sensor output and subjective votes about air quality.

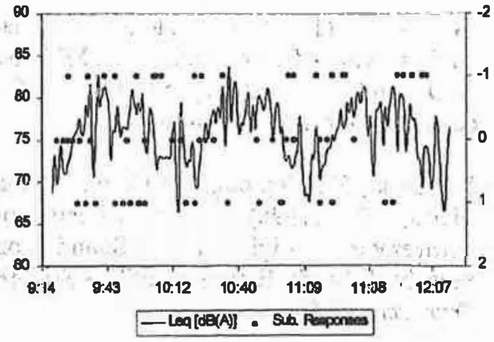

Figure 9 – Time evolution of Leq and subjective votes about Noise.

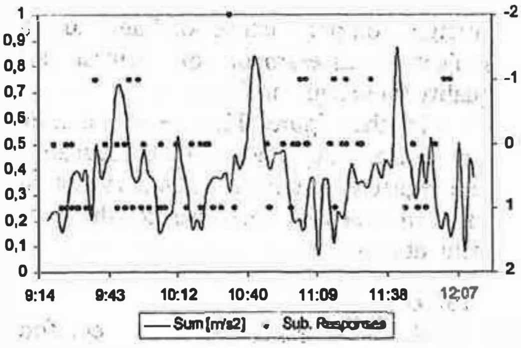

Figure 10 – Time evolution of Sum and subjective votes about Vibration.

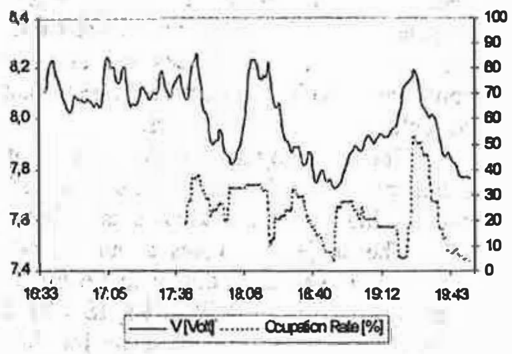

Figure 11 – Comparison of air quality sensor output with occupancy rate.

average method, with period equal to 6, shows a good parallelism with the registered PMV line.

For the other stressors, it is also possible to find some correlation between the subjective votes tendency and the physical data time evolution. It appears a three times repeated pattern in each line (noise, vibration and air quality), showing clearly that three complete turns of the bus were recorded. A downing tendency is found along the air quality evolution line, due to the decrease of the mean occupancy rate from the early morning to midday. The higher values of the sensor output correspond to a poor air quality. As a previous calibration of the sensor wasn't done, the authors can't indicate exactly the voltage output corresponding to a subjective assessment of neutral air quality (vote equal to 0).

In the figure 11, the air quality sensor line is depicted with the occupancy rate registered during the 26/02/98 test, to show the sensor response to the bio-effluent gases.

DISCUSSION

A first study on the comfort conditions in public transportation buses was conducted. Thermal comfort, air quality, noise vibration and global comfort were evaluated. The physical data necessary to compute the indices representative of each discomfort stimulus were recorded. The indices values were compared with subjective assessment collected from the passengers.

The annoyance declared by occupants was fair than it was expected, considering the measured physical values.

The subjective votes about thermal comfort showed a tendency to be higher than the calculated PMV, using ISO 7730 equations, which means that the inquired population can accept a lower comfort temperature.

Some dependency on the sociological characteristics of population was found on the subjective assessments, when comparing the data from different tests.

A further research on this subject is required to study the interference among different stimulus. More controlled test conditions are needed to have the possibility of investigating the interference between stimulus, conducting thus to the construction of a weighted comfort index. A simulation of a passenger bus compartment, in the laboratory environment, with the possibility of varying the stimuli conditions in the appropriate ranges would allow the development of this preliminary study.

ACKNOWLEDGMENTS

The authors gratefully acknowledge SMTUC, the city of Coimbra public transportation operator. The first author has done this work with a master grant from JNICT/Praxis XXI, that he gently thanks.

REFERENCES

Clausen,G.;Carrick, L.;Fanger, P. O.;Kim, S. W. , Poulsen, T. and Rindel, J. H., (1993)- "A Comparative Study of Discomfort caused by Indoor Air Pollution, Thermal Load and Noise"- *Indoor Air, 1993, 3,* pp 255-262

Griffin, M. J. (1995)- "The Ergonomics of Vehicle Comfort"- Proc. of 3rd International Conf. on Vehicle Comfort and Ergonomics, Bologna, 29-31 March

Howarth, H. V. and Griffin, M. J. (1990) - "Subjective response to combined noise and vibration: summation and interaction effects" - Journal of Sound and Vibration, 143(3), pp 443-454.

Howarth, H. V. and Griffin, M. J. (1990) - "The relative importance of noise and vibration from railways"- Applied Ergonomics 1990, 21.2, pp 129-134

ISO 2631 (1995) - Mechanical vibration and shock- Evaluation of human exposure to whole-body vibration. International Organization for Standardization, Genéve.

ISO 7730 (1994) - Moderate thermal environments - Determination of PMV and PPD indices and specifications for conditions for thermal comfort.

Yamasaki, K.; Nomoto, S.;Yukota, Y. and Murai, T. (1998) -"The Effects of Temperature, Light and Sound on Perceived Work Environment"- *ASHRAE Transactions 4167*

Viteles, M. S: and Smith, K. R. (1946). - "An Experimental Investigation of the Effect of Change in Atmospheric Conditions and Noise upon Performance" – *Heating, Piping and Air Conditioning,* 18, pp 107-112