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SOUND QUALITY OF HERMETIC COMPRESSORS AND REFRIGERATORS

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ABSTRACT

The increasing needs for products noise reduction has led to observations that A-weighted levels do not represent properly in some cases the subjective customers response to noise. Sound metrics developed for psychoacoustic analysis may provide more precise response assessments since small details in time and frequency contents are considered. This work deals with an application of sound quality techniques for the assessment of noise generated by compressors and refrigerators. Juri response to compressors noise showed very good agreement with sound power level values in dB and dB(A). Reasonably good agreement was also observed with loudness results. Other metrics did not show good correlation with juri results. Refrigerators noise levels varied by up 2dB only, which caused fairly uncorrelated comparisons to juri response. It is believed that because of the small variations in the overall noise levels juri members are influenced by small details in noise signals causing such discrepancies.

INTRODUCTION

Manufactures increased concern in recent years about the improvement necessity of products noise radiation characteristics seeking greater acceptance by the customers is well known. The development of the acoustic characteristics of products can no longer be restricted to reductions in overall noise levels since details in the frequency contents and time variations produce different reactions on people, even for equal energy (sound pressure level) signals. This work deals with an application of sound quality techniques for the assessment of noise generated by compressors and refrigerators.

Juri results of noise signals of four compressors and refrigerators were compared to the various psychoacoustic metrics results in order to identify and compare their tendencies. Juri analyses are costly and time consuming. However, such disadvantages can be overcome through calculations of the metrics provided they present good and reliable correlation to juri results. The main aim of this work is therefore to verify whether sound quality metrics could substitute juri in assessments of compressors and refrigerators noise.

METRICS OF PSYCHOACOUSTICS

The procedure usually adopted over the years for considering the subjective response of people to products noise has been the A-weighting scale which was derived from the equal loudness contour curves. Its implementation is found in most sound measuring equipments and analysers and it consists in the application of the frequency response function to the acquired signal. The weighting functions act on the signal spectrum on an energy basis only. Several other aspects of the frequency contents and details in the time history of a signal must be taken into account for a more precise subjective assessment [5]. One may therefore state that from the subjective assessment point of view the A-weighting function represents a first order approximation.

Equal loudness contour curves indicate different slope rates with frequency for different sound pressure levels. For instance, the C-weighting function derived from the 100 Phone loudness curve varies less with frequency compared to the A-weighting function, which was derived from the 40 Phone curve, located in the lower amplitude range. This amplitude effects are considered in loudness calculation by the Zwicker method, as used in this work. It considers also masking effects produced by higher noise levels in some bands upon levels of adjacent bands [1].

Fluctuation strength represents the effects caused by low frequency (less than 20Hz) amplitude modulations. Roughness represents also amplitude modulation effects, with maximum sensation when modulation frequency is about 70Hz. Sharpness considers the high frequency contents of the signal, in the kiloHertz region [1, 2].

EXPERIMENT DESCRIPTION

The test room

Refrigerators used in this experiment were placed in a 65m^3 volume test room having reverberation time carefully adjusted in order to reproduce averaged values obtained from five typical residential kitchens. The volume of a typical kitchen was considered 35m^3. A larger volume for the room was chosen to provide space to accommodate more than one refrigerator and for maintaining an almost identical distance to the sound measurement system.

Average 1/3 octave reverberation time values are shown in Figure 1. Sound absorption panels were then used in the test room for adjustment in the reverberation time. Figure 1 also shows the final values obtained.

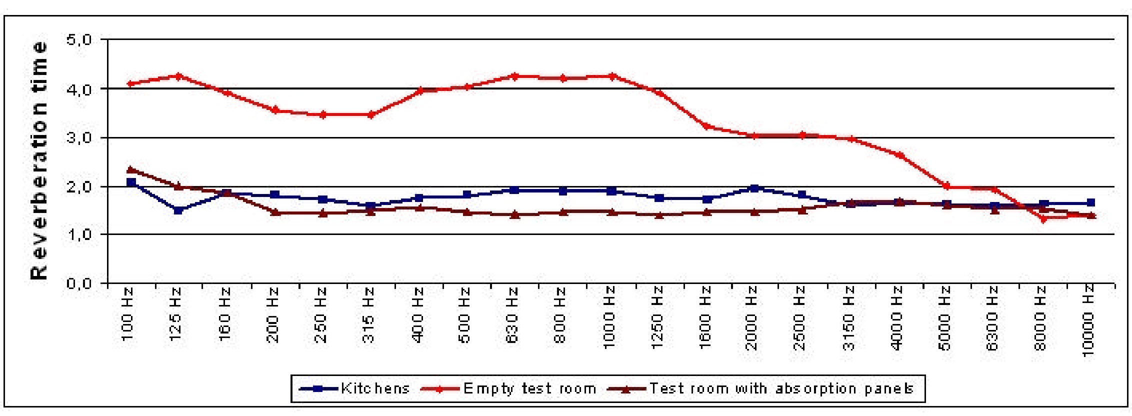

Figure 1 – Reverberation time of test room before and after absorption control, and kitchens average values.

Sound signals recording and reproduction

The advantages of recording and reproducing the noise signals are several. Signals can be reproduced several times allowing precise subjective assessments, apart from reducing time and cost. Long duration signals such as those from refrigerators, required for reaching stable standard measurement conditions, can be shortened. It also makes start and stop noise comparisons easier for the juri.

Sound reproduction can be made by use of sound boxes or earphones. The latter are preferred since they avoid room reverberations, which are generated by the sound boxes during reproduction. Another important advantage of the sound recording and reproduction procedure is the possibility of digitally editing the signals, attenuating or even eliminating any particular frequency band, or component, of interest. Digital reproduction permits one also to have a constant reference signal to be compared to other product signal.

Two different procedures can be used in this experiment for the sound signal recording. The first one uses a single microphone which yields to monaural recording. In this experiment, however, a second procedure was used making use of a head and torso simulator which represents the physical effects of the presence of a listener in the sound field. Two microphones are placed in the simulator ears for a binaural recording, which considers directivity effects [1, 3].

The acoustical characteristics of the head and torso simulator were specially developed to represent those of a typical person, including impedances of face and ears. Figure 2 shows the experiment set up and refrigerators position in the test room during measurements.

Figure 2 – General test room view with refrigerator and head and torso simulator.

Signals should preferably be submitted to a juri in pairs composed of product signal and a reference signal to be compared to. This yields to a more precise subjective judgement and any small difference between them become clearly noticeable. It was noticed that juri has great ability for detecting very small details either in time and frequency domains. Comparisons between more than two signals tend to reduce such a subjective acuity. The greater the differences in the signals, the larger the number of signals can be assessed. For compressors and refrigerators it was concluded that the recommended number for a juri assessment should not exceed four signals.

The duration of the signals presented to the juri, after several tests, was chosen to be of the order of 10 seconds, for similar signals. However, for signals having clear differences, the duration was reduced to about 5 seconds, since juri showed increased discomfort for longer durations.

Juri selection

The group of people must preferably be selected from potential product customers according to some specific criteria such as age, sex and economic classes. It is recommended that the juri should not contain any people working in the development of the acoustic aspects of the product, to avoid biased judgements. In this work twelve adult people of both sexes were invited for the juri composition. People were selected from departments of the company, not involved with the products development.

The questionnaire

A questionnaire presented to each juri member was divided into three sections. Questions related to social, economic, professional and personal aspects were presented in the first section. The subjective assessments of the noise were presented in the second section. Each juri member was asked to indicate for each signal his impression according to a four grading scale, ranging from 0 to 3, corresponding to the following subjective assessments: Unacceptable, Bad, Regular and Good. In the last section the juri members were asked to express their general impressions in written form.

The scale indicating the subjective assessment was found easier to be used and was preferred by the juri compared to the scale based on numerical indication. The development of the questionnaire followed recommendations by Borwick (1988) for the assessment of loudspeakers and vented boxes, and also comments by Lyon (1999) related to scale types and applications.

For more reliable assessments it is important to provide the juri with a comfortable environment such as room temperature and comfortable sitting chairs. Some juri members may also be influenced by external stimulus, like working during lunch time and the effects of any other psychological pressure not related to the assessment under way, which may greatly reduce their concentration. The observation of each juri member behaviour during the experiment helps to decide whether a questionnaire is acceptable or not. Juri is also not recommended to take part of long assessment sessions or repeated experiments since they may easily loose interest and concentration.

SOUND QUALITY OF COMPRESSORS

A first analysis consisted in determining which of the several sound quality metrics present better correlation to the noise of compressors. For this experiment, a set of four compressors of different models and capacities was used. Measurements were recorded in the test room using a Manikin MK1 placed 2m away from the compressors. Signals were recorded and reproduced to a 12 member jury. People were selected from central administration, production and engineering departments, not related to acoustics. Compressors were labelled C_1, C_2, C_3 and C_4. Capacity ranged from 50 to 80BTU/h. Noise signals were recorded for compressors running at standard check point (and stable) conditions, which were reached about one hour after being switched on. Figure 3 shows the juri average subjective response of the four compressor noise signals.

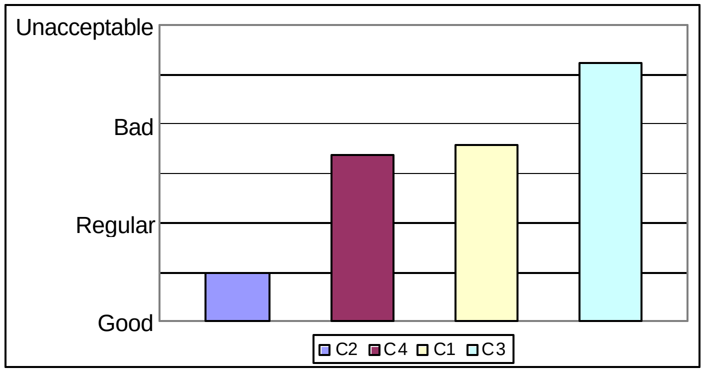

Figure 3 – Average juri assessment response to the four compressors.

Figure 4 shows a comparison of juri results with overall sound power levels expressed in dB and dB(A). It is noticed good correlation between juri results and measured sound power levels in dB and dB(A), in a very proportional way.

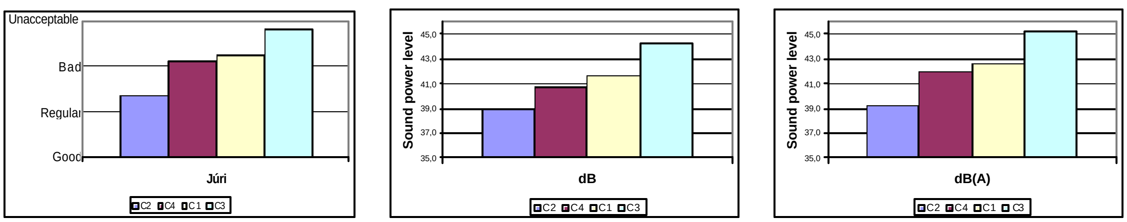

Figure 4 – Comparison between juri results and sound power levels, in dB and dB(A).

In Figure 5 it is shown a comparison of juri results with loudness, in Sone, by the Zwicker method, and sharpness (in acum) results. Loudness values present a fairly good correlation with juri results, although not as close as those obtained for sound power values, in dB(A). Sharpness values were expected to present a better correlation considering that most of the sound energy is concentrated in the high frequency range, above about 2kHz, due to shell resonances. Despite sharpness being based on the high frequency contents no correlation with juri results was observed.

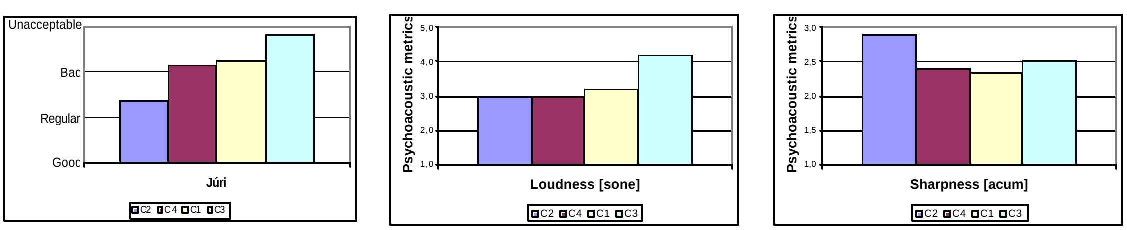

Figure 5 – Comparison between juri results with loudness and sharpness results.

Comparison with roughness and fluctuation strength is shown in Figure 6. Roughness represents the contribution of the frequency contents of a region around 70Hz. Again no correlation with juri results was observed. Fluctuation strength represents the signal amplitude modulation with frequency in the region of 4Hz. A very poor correlation with juri results was obtained.

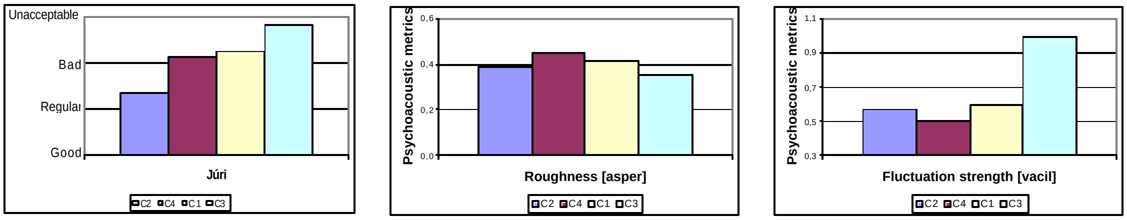

Figure 6 – Comparison between juri roughness and fluctuation strength results.

SOUND QUALITY OF REFRIGERATORS

Four different refrigerators of same model were used for sound quality assessment. The original compressors were removed from these refrigerators and substituted by those used in the previous analysis (Item 4), seeking comparisons of sound quality of each compressor when assessed individually and when installed in a refrigerator. These refrigerators were labelled R_1, R_2, R_3 and R_4. The numbers are related to the compressors labels presented in Item 4. Refrigerators of same model were chosen in order to avoid possible influences on the juri by other aspects such as colour, design and volume, for instance, apart from different mechanisms of sound generation.

Same sound quality procedure was used in this case and results are shown in Figure 7.

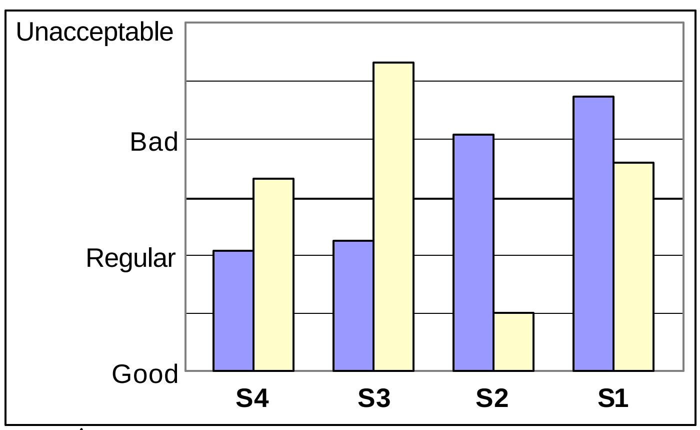

Figure 7 – Refrigerators sound quality juri assessment results compared to compressors results.

No direct correlation between compressors and refrigerators juri results was found. It is also important to notice that despite compressors sound power levels varied approximately 6.0dB (39dB(A) to 45dB(A)), the variation in refrigerators levels is only 2dB (40.5dB(A) to 42.5dB(A)). Such small variation is difficult to be detected subjectively. Noise radiated by the compressor represents perhaps the dominant source to the overall noise level generated by refrigerators. Other sources include gas flow in the system, cabinet radiation excited by vibrations generated by the compressor, and noise generated by components such as fans and electrical switches. Gas flow generated noise tends to have more unstable characteristics when compared to noise generated by the compressor.

Since refrigerators overall noise levels have close values, juri members choose their preferences based on small details in the noise signals, possibly in the time domain. This explains the poor correlation with compressors juri assessments.

A comparison between juri results and refrigerators sound power levels, in dB and dB(A), is shown in Figure 8. Juri results indicate a general tendency according to dB(A) sound power levels values. However, the correlation with values in dB scale is less evident. Loudness results shown in Figure 9, indicate also a weak correlation with juri results. Same conclusion can be drawn from sharpness results, as shown in the same figure. Fluctuation strength and roughness showed very little variation, as shown in Figure 10. The tendencies of the variations are totally uncorrelated when compared to juri results.

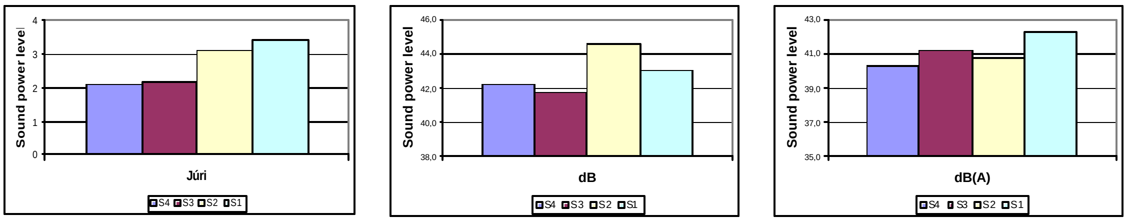

Figure 8 – Comparison between juri results and sound power levels, in dB and dB(A).

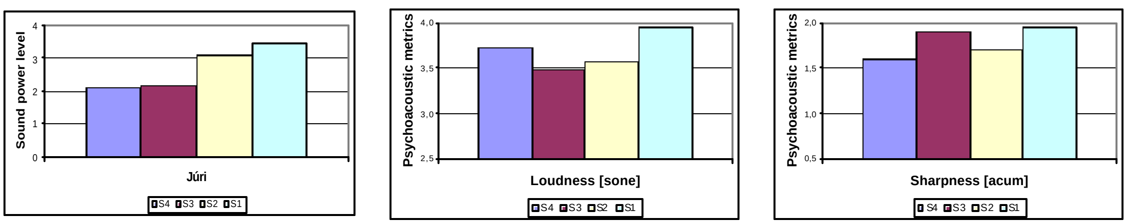

Figure 9 – Comparison between juri, loudness and sharpness results.

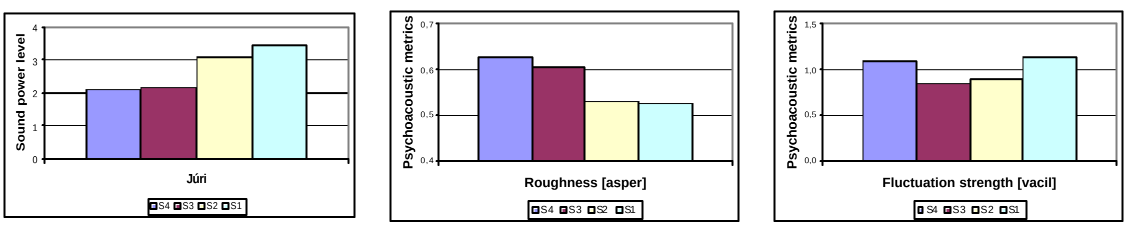

Figure 10 – Comparison between juri, roughness and fluctuation strength results.

CONCLUSIONS

Sound quality has shown to be a powerful technique for the subjective assessment of products. In this study noise generated by four compressors of different models and capacities was submitted to a juri analysis, and signals were used for the calculation of the several sound quality metrics. Juri response showed very good agreement with sound power levels, when measured in both dB and dB(A) scales, which varied by up to 6dB. Good agreement was also observed with loudness results.

These same compressors were installed in four refrigerators of same model, and their noise signals were also submitted to the same juri analysis and sound quality metrics were calculated. Sound power levels varied 2dB, only, which resulted in poor agreement between juri response and sound quality metrics results. It is believed that because of the small variation in the overall noise levels, juri members are influenced by small details in noise signals, causing such uncorrelated comparisons. This shows also important characteristics of juri analysis which is the great ability for detecting small differences in time and frequency domains, of signals having close overall noise levels.

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