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ANALYSIS OF REFRIGERATOR NOISE FOR SOUND QUALITY EVALUATION

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INTRODUCTION

Sound quality is a perceptual feature reflecting the reaction of the subject to the acceptability of product sound. Sound quality, especially in home appliances, is becoming even more important to consumers and companies as an element of the total quality concept, because consumers are ready to pay more for appliances which sound less annoying and more pleasant [1]. In fact, sound quality can be considered to be one of the most important product features qualifying home appliances such as dishwashers, refrigerators and washing machines. Factors contributing to the selection of electrical home were investigated by Kuwano et al. and the noise level was ranked the third following the efficiency and the price [2].
In this study sound quality of refrigerators is investigated. Although the noise level of refrigerators is less than any other home appliance, it becomes an important issue during the silent nighttime hours, since the refrigerator is the only working electrical appliance. Spectra of refrigerator noise are examined and some sound quality parameters are calculated in order to find out spectral differences of noise sources and their influence on calculated parameters. The purpose of this analysis is to understand the relationship between noise sources and sound quality of refrigerators. As a result, refrigerators with higher sound quality can be produced by redesigning the noise sources.

METHODOLOGY

Experiments: In this work a no-frost refrigerator is examined. Since no-frost refrigerators have a higher cooling capacity compared to other refrigerators, additional fans for better condensation and evaporation efficiency are employed. As a result, the main noise sources are the fan noises in addition to the compressor noise and the noise coming from liquids in capillaries which are common to all refrigerators. Different measurement scenarios are created to examine these noise sources:

a) fans switched off, hence only the compressor noise and noise from liquids in capillaries.
b) fans working singly, while compressor is on and off.
c) both fans working, while compressor is on and off.

Data Acquisition: The refrigerator sound is recorded binaurally in a fully anechoic room using sound quality head and torso simulator. The head and torso simulator is placed in both rooms so that its ears are 1m away from the front panel of the refrigerator and 1.5m above from the ground. After high-pass filtering (f_{cutoff}= 20 Hz), the signals are amplified by acoustic front end and then recorded by a DAT recorder. The signals are downloaded to computer digitally, where the sampling rate is f_S=24000 Hz.

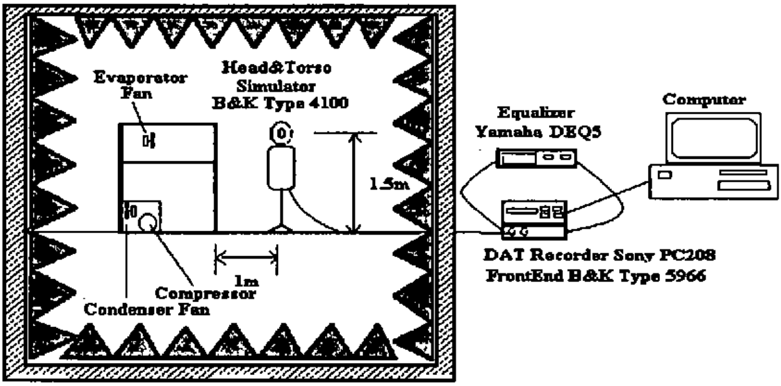

Figure 1. Data acquisition system.

Signal Processing : Power spectra of recorded signals are estimated via Welch's method [3]. The time signal x(n) is divided into 25 segments of length 4096 samples, each segment is windowed by a Hamming function w(n), their Fourier transforms are computed, and finally the magnitude spectra of each segment are averaged. Windowing helps to reduce the leakage and smooths the spectra, while averaging reduces the variance. Sound quality parameters that are examined in this study are N_{10} , sharpness and roughness. Loudness levels are found by Zwicker's method [4]. N_{10} (in sones) is the of loudness level which is exceeded 10% of time. Sharpness (in acum) is calculated using the following formula:

$$S = 0.11 \frac{\int_0^{24 Bark} N'(z) g(z) z dz}{\int_0^{24 Bark} N'(z) dz}$$

where g(z) is a weighting function that pre-stresses higher frequency components. $N'(z)$ is the specific loudness (in sones per barks). Roughness (in asper) is calculated using the method proposed by Aures in [5].

RESULTS

Comparison of spectra: • In low frequency region both fans, evaporator and condenser fan are effective. Especially, evaporator fans and condenser fans low frequency components are between 200 Hz and 400 Hz , and 100 Hz and 200 Hz, respectively.

• In high frequency region condenser fan is effective between 2000 Hz and 3500 Hz, except the peak at 2700 Hz, and evaporator fan is effective between 4800 Hz and 5000 Hz.

• The evaporator fan has 4 blades and is rotating with a frequency $f_{evap} \approx 47$ Hz. The condenser fan has 3 blades and is rotating with a frequency $f_{con} \approx 34$ Hz. Using the relation between fundamental frequency, blade number, N, and rotation frequency of fan ($f_{fund} = Nf_{fan}$), fundamental frequencies of fans are found to be approximately 200 Hz and 100 Hz, respectively. As a result, the harmonics of both fans are overlapping, which prevents to relate harmonics to individual fans.

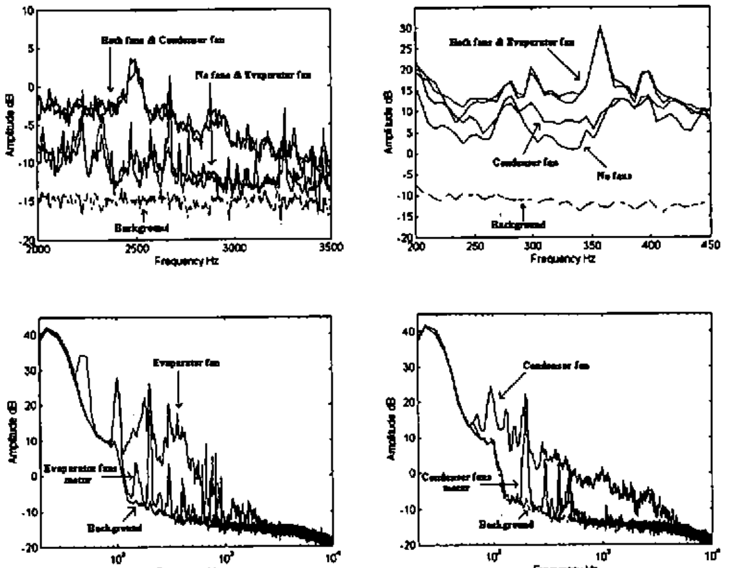

Figure 2.(a,b) Parts of spectra where the effects of fans on overall spectrum can be distinguished easily. (c,d) Spectra of evaporator and condenser fans and their motors.

Comparison of sound quality parameters: • N_{10} value becomes maximum, when both fans are working, and becomes minimum, when both fans are switched off. The contribution of fans to the loudness level is approximately equal to the contribution of compressor and liquids in capillaries. N_{10} value of evaporator fan is slightly higher than N_{10} value of condenser fan.

• Roughness values for all different measurement conditions are approximately 0.1 asper. So the conclusion can be drawn that the roughness value is not affected by different noise sources in a refrigerator.

• Sharpness becomes maximum, when condenser fan is working singly, and becomes minimum, when evaporator fan is working singly. Since sharpness is a parameter giving information about high frequency content, this result was expected because condenser fan has more energy in high frequency region compared to evaporator fan.

Table 1. Sound quality parameter for right and left ears in FAR while compressor is working (C: condenser fan , E: evaporator fan)

Ear	Right Ear			Left Ear		
Working Fan	N_{10} (Sone)	Roughness (Asper)	Sharpness (Acum)	N_{10} (Sone)	Roughness (Asper)	Sharpness (Acum)
C+E	1.04	0.10	1.23	0.91	0.10	0.94
E	0.88	0.10	1.26	0.73	0.10	0.91
C	0.80	0.10	1.43	0.64	0.10	1.10
-	0.63	0.12	1.41	0.36	0.12	1.04

Table 2. Sound quality parameter for right and left ears in FAR while compressor is not working

Ear	Right Ear			Left Ear		
Working Fan	N_{10} (Sone)	Roughness (Asper)	Sharpness (Acum)	N_{10} (Sone)	Roughness (Asper)	Sharpness (Acum)
C+E	0.52	0.09	1.01	0.54	0.10	0.99
E	0.30	0.09	0.81	0.30	0.10	0.85
C	0.27	0.10	1.30	0.29	0.10	1.24

CONCLUSIONS

In this work refrigerator noise is investigated in order to see the affects of different noise sources on the total noise of the refrigerator and on some sound quality parameters. Results of investigation showed that sharpness and N_{10} values are affected by different noise sources in the refrigerator. In order to achieve better sound quality from refrigerators, attention must be paid specially on the design of fans in the refrigerators. However, for sound quality evaluation of home appliances the currently used metrics are insufficient, and more perceptual features of the noise will be examined for a better description of sound quality of household refrigerators. The validity of these new features will be checked by jury listening tests.

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