Noise perception of wall-hung gas boilers

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The aim of this study is to assess the quality image for domestic wall-hung gas-fired boilers, based on their noise. Nine boilers were recorded using an acoustic manikin in a hemi-anechoic room, for different operating conditions. Two of these operating conditions (maximum heat input, hot water tapping) were first studied. Five-second sequences were presented (through headphones) to sixty listeners using the mixed assessment method allowing for the comparison between signals. Analyses showed several assessment strategies: according to listeners, the relevant noise parameters could be the loudness, the sharpness or the presence of tonal components. A second experimental phase focused on tonal components by artificially modifying some sounds to offer a relevant perceptive indicator. The results of this second experiment will also be presented.

1   Introduction

Wall gas-fired boilers are a very common feature in apartments and houses. Their noise emission levels are weak (typically lower than 40 dB(A)). Aside from dysfunctions (failure or bad installation), noise generated by boilers is rarely disturbing for people living in the house. However, like for many other instruments, sound can convey an image of quality for this equipment. The work presented here is part of a broader study led by the CETIAT (Technical Centre for the Heating, Ventilation and Air-Conditioning Industries) on the account of wall boiler manufacturers and aiming at recommending perceptive targets for the noise generated by these machines. Under normal operating conditions, the noise is stationary (continuous speed) and non-stationary (*e.g.*, the burner is triggered when sanitary or heating hot water is required). However, the study first focused on stationary operating phases, in order to use proven approaches to assess the sound quality of mechanical instruments.

2   Recording and preparation of stimuli

Nine wall boilers of different manufacturers were used. Each one was placed in the CETIAT's semi-anechoic room, with a very small background noise, in realistic operating conditions (including, in particular, water circulation). Speed or operating changes were controlled from outside the chamber and very little unwanted noise actually disturbed the recordings.

A 01dB-Metravib acoustic manikin (Cortex HATS) was placed 1 meter in front of the boiler in sitting position (Fig. 1) and recorded (fs = 48 kHz) complete operating cycles of the device (start-up, several heating modes, several sanitary hot water production modes, then shutdown). Each recording lasted about thirty minutes.

Two operating conditions were first selected: the first one deals with the production of sanitary hot water (hereafter called condition A), while the second deals with the production of hot water for heating (condition B). Five-second samples were collected for each boiler, after checking with a calculation of usual perceptive criteria, that the signal from which they were extracted was stationary. After suitable filtering [1], excerpts could be presented to listeners.

Figure 1: Recording of a wall boiler

3   Perceptive experiments

In order to limit experiment time while keeping good accuracy for the results, it has been decided to use the so-called "mixed" method, which consists in asking each listener to assess each sound on a continuous scale, while listening freely to all sounds (which favours the comparison between them). A first experiment [2] had indeed showed that this method allowed for a good trade-off between quick assessment and accurate pair comparisons, which was later confirmed for other types of sounds [3].

The tool used for these experiments is the Jury Testing software developed by the 01dB-Metravib company. The listener's task was to assess the **quality of the boiler** as conveyed by each sound. This question was displayed on a computer screen (Fig. 2), which also showed the response scales. Stimuli had previously been arranged in random order and, by clicking on the small green triangle to the left of the scale, the listener could listen to the corresponding sound as many times as he/she wished to.

Two experiments were carried out (one for each operating condition), to which 59 persons took part. The jury included 30 men and 29 women. 30 persons were aged 30 to 45 and 29 persons 45 to 60.
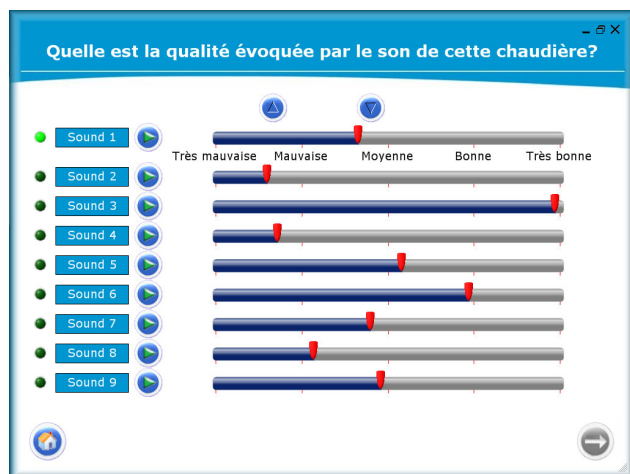
Figure 2: Perceptive test screen
(Question: What is the quality suggested by the
sound of this wall boiler
Legend: Very bad / Bad / Medium / Good / Very good)

Figure 3: Assessment of the nine boilers
in two operating conditions

4 Results analysis

4.1 Subjective assessments

Listeners answers were coded as numbers ranging from 0 (meaning "very poor quality") to 1 ("very good quality"). The first observation consisted in comparing boiler results in the two conditions (Fig. 3). The figure below shows the average values, as well as the uncertainty range of this average ($p = 5\%$). Assessments for some machines are very different (see, *e.g.,* boilers 2, 5 and 7).

For the rest of the study, it appeared that the use of response scales could strongly vary depending on listeners. For instance, if one looks at the average of the evaluations given by a listener for all sounds, this value can range from 0.2 ("poor quality") to 0.7 ("good quality"). It was then decided to work with the reduced centred data of each listener.
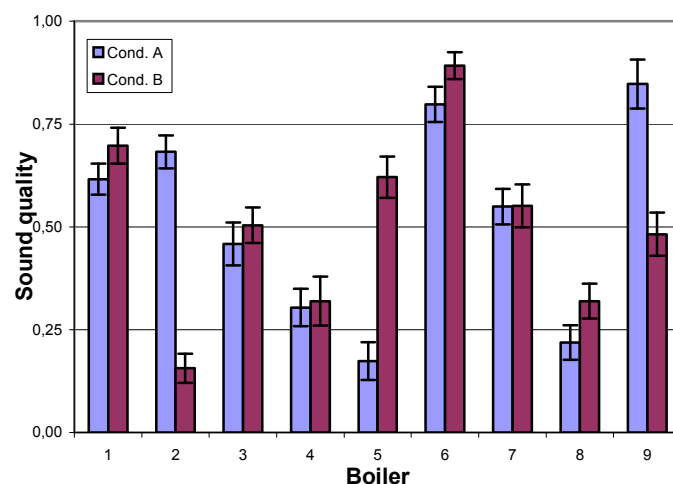
Prior to each experiment and for a better understanding of the "quality of boilers", the listeners were asked to imagine himself as an apartment owner who had a new boiler installed. His/her task was then to assess whether the noise gave him/her the impression of a quality machine, deserving its price or conveying the feeling of long-term no-problem operating. The nine sounds (for a given condition) were then presented to the listener, through Sennheiser HD600 electrodynamic headphones. Finally, the experiment itself could start. One of the interesting points of the implemented method is that it is quick: about 10/15 minutes only were required by each listener to assess the nine sounds, even when listening to each sound several times.

First of all, and for each operating condition, an ascending hierarchical classification (Ward's method) was performed to search for homogeneous listener groups. It appeared that:

- in condition A, listeners gave very homogeneous answers, except for six persons, which were excluded from the panel, since they were too few for any analysis.

- for condition B, two groups could be created. The first group includes 39 persons giving very homogeneous answers. The second group (20 persons) is less unanimous, as shown by the larger uncertainty ranges of average values calculated for this group (Fig. 4).
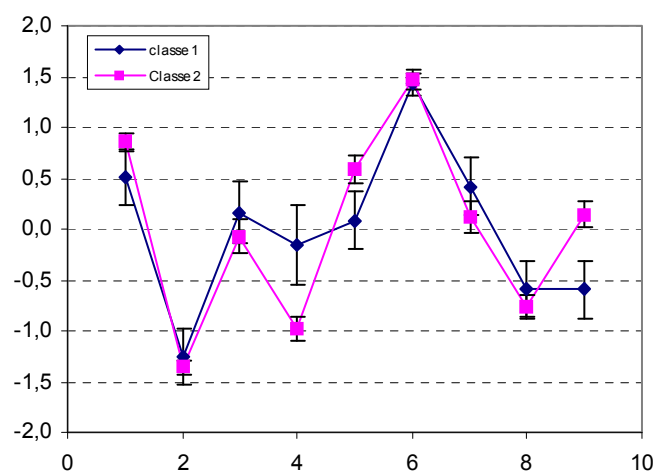

Figure 4: Sound quality for the two sub-groups
(condition A).

4.2 Search for models

Different indicators were calculated by software dBSonic (01dB-Metravib), based on the signals recorded by the manikin (equivalent levels, loudness, sharpness, Tone-to-Noise Ratio, etc.). Simple models allowing representing the evaluations were searched for, based on these indicators. To do so, we used the ascending linear regression method (implemented by software SPSS).

For condition A, the perceived level is clearly the dominating factor for the sound quality mentioned: the correlation coefficient between listeners' evaluations and the overall level in dB(A) is R = -0.89. The correlation is even better between the evaluation and the loudness (measured according to Standard ISO 532B): R = -0.97 (Fig. 5).
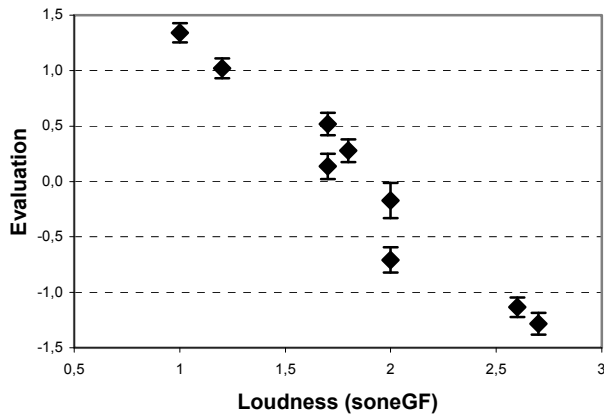

Figure 5: Relation between loudness (ISO532B) and evaluation of the boiler quality (condition A).

For condition B and the majority listener class, the relation between loudness and evaluation is not as good (R= -0.84). Based on discussions with the listeners, it turned out that the presence of emerging frequencies could contribute to the degradation of sound quality. Such emerging frequencies were detected by an indicator like the Tone-to-Noise Ratio. The principle of this indicator [4] is to add a penalty to the global sound level (expressed in dB(A)) if the emergence exceeds a defined threshold. In our study (like in many others), the loudness indicator proposed by E. Zwicker has turned a better indicator for the subjective loudness than the overall level. We have therefore proposed to change this loudness value with the penalty resulting from the TNR, using the following formula:

$$Sonie\_pena = Sonie.2^{Penalty/10}, \qquad (1)$$

which allows respecting the relation between loudness and equal loudness level, comparable with decibels for a pure sound of 1000 Hz.

This indicator has allowed for a significant improvement of the representation of experimental data (R = -0.94), as shown in Figure 6.
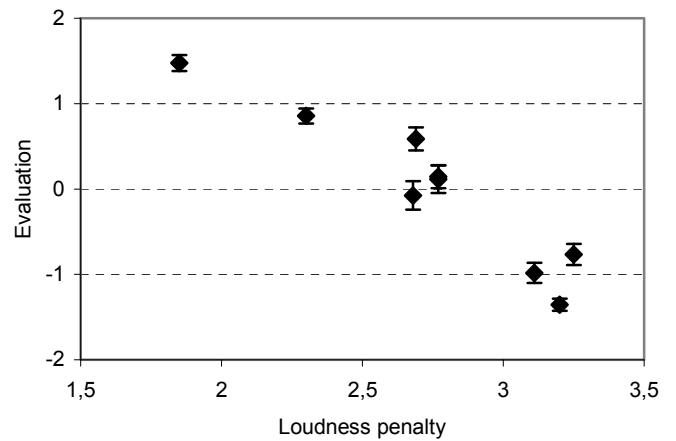

Figure 6: Relation between loudness modified according to TNR penalty and evaluation of the boiler quality (condition B).

This indicator can also be used to represent evaluations of the minority listener class, but with a lesser accuracy, which can result in part from the greater variability between listeners that was observed in this group.

5   Conclusion

This paper shows an example of a practical methodology for understanding the perception of boilers' sounds. This study identified the sound features which are important for the evaluation of sound quality. Using the so-called mixed method allowed a short experiment time while providing accurate enough subjective data and this method can be recommended in most sound quality studies conducted in industry. The analysis of subjective data showed the importance of sound level, as could be expected, but also of emerging frequencies. Though an attempt to take these frequencies into account has been proposed, by modifying loudness values with the penalty computed according DIN 45681 standard, some more work is needed in order to validate this indicator.

Reference

[1] H. Möller, "Fundamentals of binaural technology", *Applied Acoustics*, 36 (1992), 171-218

[2] E. Parizet, N. Hamzaoui, G. Sabatié, "Comparison of some listening test methods: a case study", *Acustica united with Acta Acustica* 91 (2005), 356-364.

[3] P. Chevret, E. Parizet "An efficient alternative to the paired comparison method for the subjective evaluation of a large set of sounds", *ICA 2007* (Madrid)

[4] DIN 45681-2002 – "Acoustics - Determination of tonal components of noise and determination of a tone adjustment for the assessment of noise emissions".