Sound quality evaluation of kitchen hoods

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Abstract

The main goal of present work is to create a comparative evaluation methodology based on the correlation between the objective parameters of traditional acoustics and the psychoacoustic subjective parameters investigated with listening tests. This led to the definition of a quality index for kitchen hoods calculated from measurable objective parameters to provide guidance on the ultimate sound perception of the consumers. The acquisition of data was carried out in a standardized laboratory and in a typical environment representative of a kitchen, in order to study the acoustic behavior of the hood installed and operating in real conditions. For this reason, suitable listening tests have been conducted on a selected group of subjects representing a sample of potential clients of the selected kitchen hood models, with the aim of correlating human sensations and measured objective parameters. Finally, a sound quality index (SQ Index) was calculated for each of the hood models in order to highlight the best performing sample from the point of view of the pleasantness of the sound emitted in the kitchen environment.

Keywords: `sound quality, psychoacoustic measurements, auditory testing, statistical analysis, kitchen hoods`

1. Introduction

In recent years, the scientific community has shown an increased interest in sound quality analysis and sound design. Sound quality studies have been often developed during the acoustic characterization of industrial products. Research suggests that sound quality studies associated with sound-design represent an engineering procedure taken into great account by companies during product development. In this work, the focus is on the acoustic noise produced by kitchen hoods. Kitchen hoods are an essential component of household appliances, as they are able to capture fumes and vapors during foods preparation. Over the years, manufacturers have worked to define the mechanical characteristics of the hood in order to make it as adaptable as possible to the needs of the consumer. The main challenges faced by R&D departments are energy consumption, air flow values and speed profiles. A literature background on this topic is provided in the following section, together with some details on the contribution of the related works.

1.1. Background

J. Abanto and M. Reggio conducted a study focusing on the airflow propagation of hoods by creating numerical models of computational fluid dynamics[1]. Kuhn et al.[2] have highlighted the problem of disposing the exhaust fumes produced by the hood, which are dispersed in the environment. The researchers investigated the effectiveness of indoor levels of ultra fine particles (UFP) emitted from a gas stove and oven[3,4]. In addition to being electro-mechanically efficient, the kitchen hoods have not to be noisy. The sound quality assessment is an important factor when trying to boost product credibility in the market. In the product certification phase, the sound power and sound pressure levels are measured, but to evaluate the sensation of the consumers it is necessary to consider other acoustic metrics. Generally, the acoustic metrics are divided into two macro areas: traditional and psychoacoustic. The traditional metrics[5] used for characterization of sound power levels offer quantitative informations about the sound, while the psychoacoustic metric system provides informations about sensations, pleasantness and tone of sound[6–8]. Psychoacoustic metrics were developed by Zwicker[9] who proposed a model for combining several psychoacoustic metrics into a single metric to quantify annoyance. Sound quality studies were carried on in the automotive industry focusing on the study of noise resulting from the door closure of a vehicle[10]. This type of noise offers two good indications: the first is if the door has been closed properly, the second indicates that a good thud will contribute to the overall impression of the car, and this is a very important factor since closing the door is an action that a customer may do while looking at the car in the seller shop[11]. Many publications report

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sound quality studies about the noise emitted by a door that slams, but the methodology of this kind of listening experiments is not clearly explained[12–14]. In [9] are presented collections of data describing the processing of sound by the human auditory system. The work includes quantitative relationships between sound stimuli and auditory perception, providing quantitative psychoacoustic models of auditory perceptions. Based on the metrics defined in [9], Gierlich[15] has created a qualitative model founded on the correlation of the perception of binaural tone with the auditory profile of the individual listener. In a study of dishwashers[16], Lyon[17] identifies the reduction of the sound power level as the main goal of the research. During the study the calculated acoustical metrics where also correlated with the decision of the user. In addition to dishwashers, similar studies have been conducted on washing machines. After the optimization of the impeller design was possible to optimize the sound quality of the product[18].

1.2. Contribution of this work

The research on the psychoacoustic metrics is very important in order to determine the sound quality of the product. The quality aspect of sound produced by industrial prototypes is perceived subjectively and is related to the individual user. The designer needs to optimize the product sound to the target customer group, whose taste is not consistent and will change over time as fashion. Working with the sound quality is an iterative process. The first step it is the acoustic characterization of prototype of an industrial product, make the recordings of the sound from prototypes and at last get the first evaluation from a listening test with a jury representing the final users of the product. If there is a match between the measure of acoustic characterization and the sensibility of the listener, the iteration is closed. This work on the sound quality of the product is mainly concerned with the relationship between the work of the designers and the perception of the consumer about the acceptability of the sound emitted. In the light of the state-of-the-art described above, the innovation carried out by this work relies on the proposal of a complete methodology for determining an index for hoods sound quality. In particular, the method combines objective measure and signal elaboration for noise detection. The paper is organized as follows: Section 2 presents the kitchen hoods, and it is focalize on the mechanical functioning and acoustic characterization. In Section 3 the focus is on acoustic listening tests, whereas Section 4 presents the statistical analysis. The simulation results are reported and discussed in Section 5. Section 6 draws the conclusions of the work.

2. The kitchen range-hoods ad acoustic characterization

The kitchen hood is a household appliance that aims to eliminate fumes and odors emitted while cooking food. The Kitchen hoods are classified into aspiring hoods and filtering hoods. This classification is done purely on the basis of how the hood processes the air that is being sucked based on the standard IEC 61591[19] that defines the main performance characteristics of range hoods and specifies the methods for measuring the product characteristics. There are two types of hoods: aspiring and filtering kitchen hoods. Aspiring kitchen hoods [fig.1S] are the most common and a primary type of kitchen hoods; an aspiring kitchen hood has a duct that is used to process and expel any smoke that is generated on top of the kitchen hob. Filtering kitchen hoods [fig.1F] do not have a duct that is used to process the air. Instead, this kind of hood makes use of strong air filtration and then pumps out the air back into the room. These types two of range hoods are most commonly used in private houses. In this research were used kitchen hood in filtering mode.

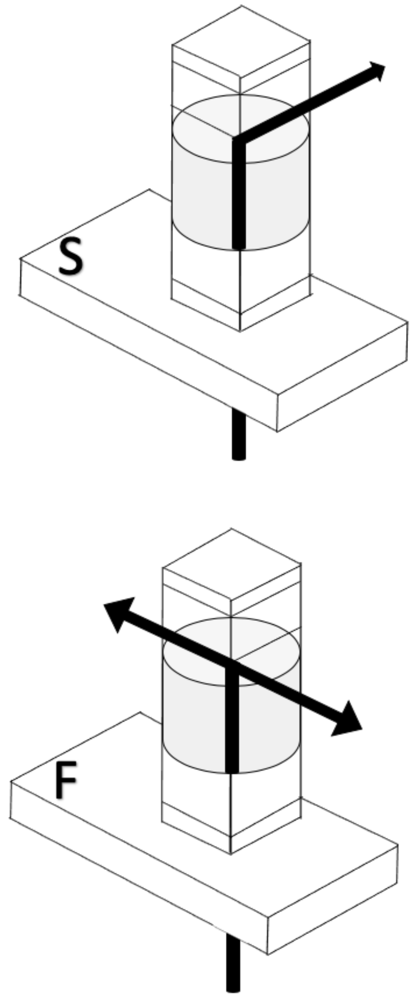

Figure 1: Kitchen hood in suction(S) and filtering(F) mode

In the experiments to be discussed below, a sample of four hoods has been chosen, representative of the production line. The samples chosen for the measurement were selected based on volumetric flow rate, pressure level dB(A), absorption and energy label class. These four samples all belong to the same energy class, as seen in fig.2. The measures of interest for this analysis are those related only to the sound emission of the kitchen hood. The standard IEC 61591[19] and the ISO 3741[20], ISO 3744[21], ISO 3745[22], ISO 3747[23] had been taken as references for the calculation of the noise. The samples were named as C1, C2, C3, C4 to preserve the company privacy.

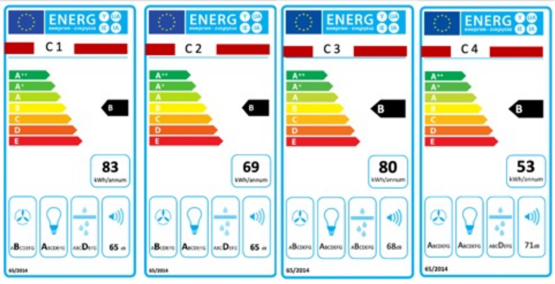

Figure 2: Energy label of kitchen hood samples used in the current experiments

The measurement of the sound power level expressed in dB(A) was done in the reverberation chamber according to ISO 3741[20] and in silent chamber by sound intensity probe SINUS SIS190, according to ISO 9614-1[24]. For the subjective investigation, the reverberation condition could have influenced the result. At the same time, binaural acquisition[8], was conducted in the silent chamber[21,22]. The silent chamber is used for acoustical experiments requiring a free-field environment. The data acquisition was carried out using the sound intensity probe, the hood was placed inside the chamber according to the constraints imposed by the standard. Setup of C1 is shown in fig.3. The other samples are evaluated following the same procedure.

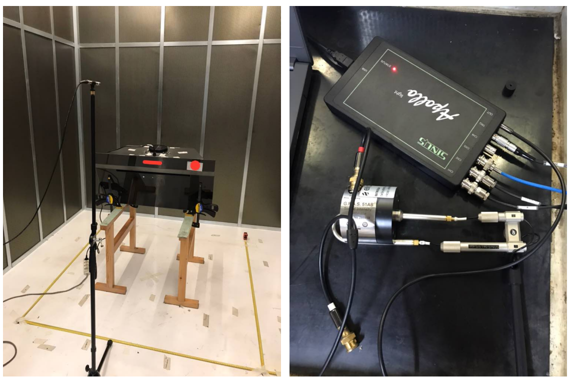

Figure 3: Setup of samples for sound intensity calculation

In accordance with the standard ISO 9614-1[25] the test configuration requires a distance of at least 1 m between hood (including protruding parts) and all elements in the silent room (walls, diffusers, absorbent panels, microphones and easels). The diagram in fig.4 represents the A-weighted sound power and sound pressure level in silent chamber for sample C1. The other samples are evaluated following the same procedure.

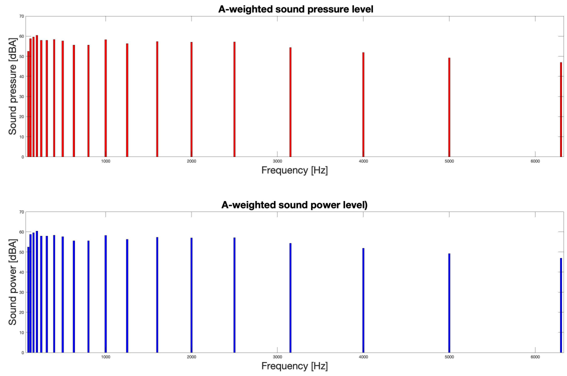

Figure 4: A-weighted sound pressure and sound power level for sample 1

3. Binaural measurements

The acquisition of the objective parameters of psychoacoustics was carried out within a kitchen environment set up within the company laboratories as seen in fig.5. A representative test in listening conditions was created with typical installation environments.

Figure 5: Binaural measurements in the kitchen environment

Experimental measures allowed the determination of acoustic parameters such as sound pressure levels (SPL) and the main objective parameters of psychoacoustics: Loudness, Sharpness, Roughness, Fluctuation strength[26–28]. The sound levels for the calculation of the psychoacoustic parameters have been measured thanks to head and torso simulator, type 4100 with preamplificator type 5953. Head and torso simulator is equipped with two microphones positioned to the ear canals on the manikin head to simulate the separation that exists between the right ear and the left ear of a human head. In order to develop the methodology, after a preliminary analysis of the collected data, Loudness, Sharpness and weighted sound pressure level-A were taken into account. The sound pressure level (as see in equation 1) is a logarithmic measure of the effective sound pressure of a mechanical wave referring to a reference sound source:

$$L_p = 20 \cdot Log \frac{p}{p_0} [dB] \tag{1}$$

Loudness N is the integral of specific loudness over critical-band rate (as see in equation 2). In [29] the specific loudness was explained like a sensation belonging to the category of intensity sensation; the specific loudness grows with physical intensity according to a power law. In consequence of this law, it was assumed that a relative change in loudness is proportional to a relative change in intensity. Specific loudness is developed using this power law like this mathematical expression:

$$N = \int_0^{24bark} N' dz, \tag{2}$$

The sharpness (as see equation 3) has been modeled taking into account loudness and considering a narrow band noise centered at 1 kHz:

$$S = 0.11 \left(\frac{\int_0^{24} N' g(z) z dz}{\int_0^{24} N' dz} \right) \tag{3}$$

The graph in fig.6 shows small gap between the parameter values measured in the left and right ear, so it was chosen to consider the mean value.

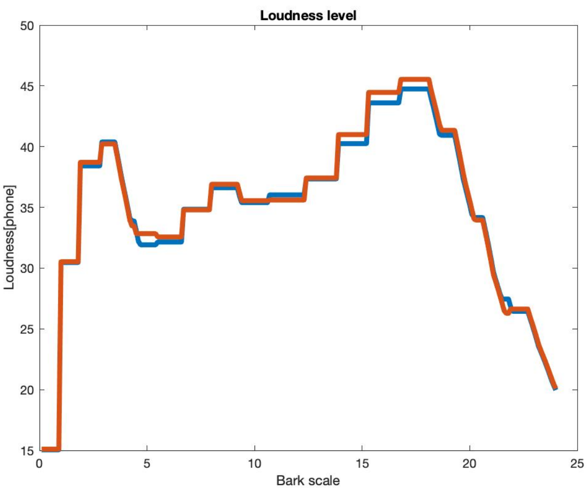

Figure 6: Loudness level between value measures in the left and right ear

Consistent with fig.6 findings, tab.1 shows the numerical values of Loudness, Leq and Sharpness for all samples at the first speed and at the third non-intensive. Henceforth to indicate the sample and the speed of repetition the acronym CnVm was used, n representing the sample number and m representing the test speed.

CnVm	Leq [dBA]	Loudness [Phone]	Sharpness [Acum]
C1V1	64,3	82,156	3,131
C1V3	66,8	84,163	3,354
C2V1	52,2	70,609	2,371
C2V3	64,2	81,063	3,161
C3V1	57,3	75,342	2,441
C3V3	65,2	83,063	3,005
C4V1	39,1	55,312	1,382
C4V3	57,4	76,033	2,275

Table 1: Leq, Loudness, Sharpness - average values

4. Listening test

Subjective tests were carried out following the advice provided by the ITU-R BS 1116-3 recommendation[30]. The jury of listeners was given two types of tests, the first (T1) focused on the assessment of the pleasantness of the sounds, the other (T2) able to define a hierarchical scale of liking, for all samples and for the two speeds tested. Both questionnaire were used to assess listeners emotional sensation about the sound. Listeners were chosen from employees, students and professors from the Università politecnica delle Marche. The first listener can be considered trained to listen to the hoods noise, the others are less influenced listeners. The age ranged from 20 to 65 years. None of the selected people had previously participated in acoustic evaluation tests aimed at studying a product. The fig.7 shows the variety of listeners.

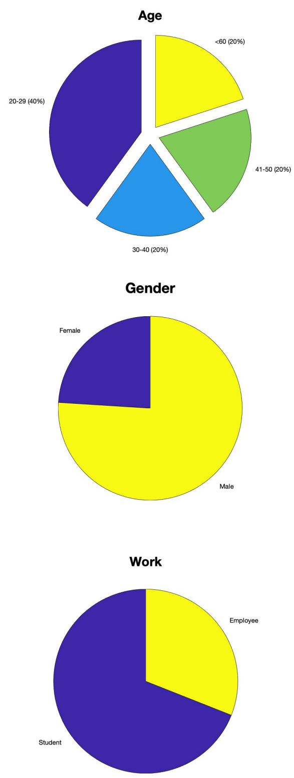

Figure 7: Pie chart that defines the variety of listeners

Does the kitchen hood provide excellent sound quality?
Is the cooker hood noisy in the kitchen?
According to the noise level of the kitchen hood, how much would you attribute in terms of perceived volume?
Will the sound of the cooker hood affect your purchase?
Does the kitchen hood offer a pleasant sound in terms of acoustic comfort?
Is the sound of the kitchen hood in line with your expectations?
Does the sound of the cooker hood give you the idea of an expensive product?

Table 2: T1: Listening test question

4.1. Test method

Subjective assessment methods are used to establish the sound performance of kitchen hoods measuring the reactions of those who might use the systems tested. There are assessments that establish the performance of systems under optimum conditions and for this reason test T1 was carried on in the kitchen. This setup was realized in order to stimulate a judgment by listeners in the condition of real installation. During the test, to avoid distraction elements, the hood was covered with black sheets. At the beginning of each session, an explanation was given to the observers about the type of assessment, the grading scale, the sequence and timing. The listener was positioned at the distance of 1 meter from the range hood for 30 seconds. After listening to each sound, the listener was asked to evaluate it by filling out a questionnaire of 7 questions. The jury was asked to answer the questions by indicating the degree of preference with a grade normalized in a grade scale from 1 to 5. Tab.2 shows the questions of T1 test. The subjective experiments are characterized primarily by control and manipulation of the experimental conditions, and secondly from the sensations coming from the human observers. The questions were designed specifically for the case study. The ultimate aim was to understand how much the listener perceived in terms of quality, noise, pleasantness and tone of the sound of the product. The quality refers exclusively to the product: it must be investigated the degree of satisfaction that the consumer expresses in relation to the product. The pleasantness refers to the perception that the listener has of the sound heard. The T2 test was built in comparative mode and was administered to listeners through an online Google form[31], a tool collecting information from users by personalized survey using audio tracks captured in the kitchen environment. Each listener had the series of tracks available before starting the test and was able to repeat the listening at will before proceeding with the evaluation. Before the start of the test, the listeners have been involved in a brief session for discussing the test mode. It was asked to the listeners to rank the eight sounds in term of pleasantness, indicating for each the degree of liking on a normalized scale from 1 to 5.

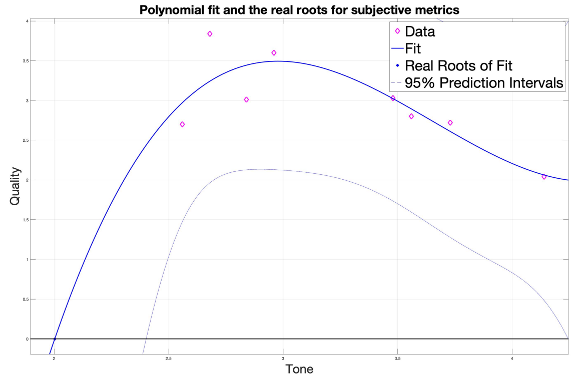

Figure 8: Results of polynomial regression between Quality and Tone. Several noteworthy results were: Correlation 0,99; Covariance 0,40; Probability 0,001.

5. Statistical model and curve fitting

The topic of this work is to identify the most effective correlation between the psychoacoustic parameters and the responses of subjective tests. The purpose of the correlation study is to highlight an interdependence link between the statistical variables. The linear correlation is measured by Bravais-Pearson[32,33]. The correlation coefficient between two random variables X and Y is defined as:

$$\rho(X,Y) = \frac{\mathbf{Cov}(X,Y)}{\sqrt{\mathbf{Var}(X)\mathbf{Var}(Y)}} \tag{4}$$

The models for acoustic quality assessment will also be proposed. Each answer collected with the T1 test has been was normalized, by calculating the average sample response, and analyzing the dispersion of the results through the evaluation of standard deviation[34]. First, it was verified that subjective metrics were not unrelated to each other, so understanding how much the answer to a question may be related to the answer to another question. The polynomial regression analysis was used to identify the most appropriate correlation. Approximate curves can be used to visualize data and to summarize the relationships between two or more variables. For this analysis a third-degree polynomial curve was chosen, and for example, a representation of the curves with relative values of the correlation coefficient between the subjective metrics is reported in fig.8 and the correlation coefficient between the objective metrics is reported in fig.9.

The correlation of Pearson is explained in equation 4, the covariance represents the variability of two variables and the probability represents the prediction interval.

Observed at the statistics, one can see that there is a close correlation between the questions submitted to the listeners, so the analysis could be carried out to identify the degree of correlation between psychoacoustic and subjective metrics[35, 36]. Taking into account the statistical data, it can be surmised the sound quality index that

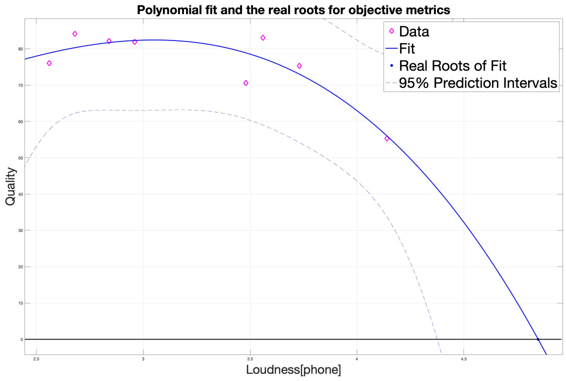

Figure 9: Results of polynomial regression between Quality and Loudness. Several noteworthy results were: Correlation 0,70; Covariance 3,80; Probability 0,051.

can be reached through statistical inference methods. The correlations were calculated considering the average values between right and left ear. Tab.3 summarizes the correlation of Pearson between subjective and objective metrics and shows the results of the polynomial regression. Based on the existing literature the results show an acceptable correlation between the metrics in exam. In the study are considered only correlations with a coefficient of Pearson greater than 0,65.

	SPL	Loudness	Sharpness
Quality	0,69	0,70	0,64
Noisiness	0,74	0,75	0,71
Pleasantness	0,83	0,85	0,81
Tone	0,77	0,76	0,86

Table 3: Values of the coefficients of Pearson

6. The sound quality index

To build a custom metric for the case study, a multivariate regression model realized in the Matlab environment (R2018b-64bit) was exploited[37]. The regression model consists in correlates two or more variables (objective metrics) to the dependent variable (see equation 5).

$$YFIT = b(0) + b(1) * Leq + b(2) * Loud + b(3) * Sharp \quad (5)$$

where $YFIT$ is the response variable, bn represent partial regression coefficients:

- b(0) = 9,5608
- b(1) = 0,2708
- b(2) = -0,2821
- b(3) = -0,4691

The fig.10 shows the multivariate regression pattern between the subjective metric and the objective parameters. The choice was made based on the degree of the correlation of Pearson obtained by the polynomial regression between the individual metrics. The same operational methodology was done for all the metrics described above for all available samples.

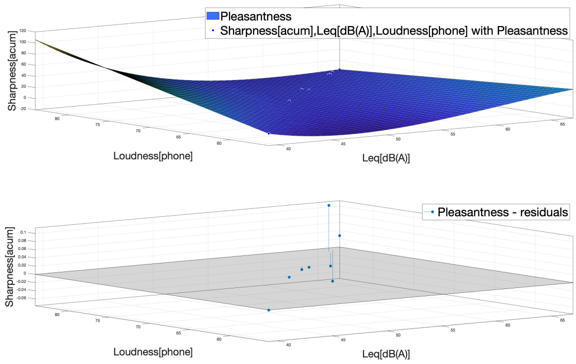

Figure 10: Multivariant fitting between the pleasantness and the psychoacoustic metrics

The SQ Index was defined as the weighted sum of the subjective metrics investigated, the weights were assigned on the basis of the value obtained in the bivariate correlations and as a discriminating element the Pearson correlation coefficient was chosen. The results of the T2 test were used to validate the model.

Rate	Samples	SQ-index	Result T2
1	C4V3	0,073	3,94
2	C3V3	0,335	3,05
3	C2V3	0,426	2,91
4	C1V3	0,501	2,11

Table 4: Calculated the SQ Index comparison and the T2 comparative tests

Taking into account the statistical data, it can be surmised that the model showed a positive match for all samples tested at the third non-intensive speed. In particular, the same hoods rating was obtained, both with the comparative subjective method and with the method based on the SQ Index.

7. Conclusions

To date the literature has offered many contributes about sound quality studies of industrial products. This work provides a complete methodology to determining a SQ Index for kitchen hoods. It was identified a representative sample of kitchen hoods. The acoustic characterization of the products has been done in controlled acoustic rooms using also binaural techniques. It was defined a listening test suitable for the case study and a listeners group was selected. The statistical survey allowed us to discriminate the data obtained from the listening tests in order to obtain an accurate result. Finally, it was realized the calculation of the sound quality index through the correlation of subjective with objectively measurable parameters. For the calculation of the custom metric, a multivariate regression model, specifically built for the case study in the Matlab environment, was used. The custom equation resulting from the multivariate regression represents the mathematical instrument for the calculation of the sound quality index. The index defined allows to predict the sensation of listeners for the samples under analysis about kitchen hoods noise. Naturally, the problem of the acoustic optimization of a product does not end with the analysis of the psychoacoustic descriptors but it has to be combined with the mechanical and fluid dynamic analysis. The proposed methodology has however highlighted the noise characteristics that influence the evaluation of the consumers. In conclusion, the procedure applied in the study, both mathematical approach and data processing, could be seen as a reference point for the design of a good product during prototyping. It would be useful to improve the research project in this way: first of all, it may be possible to test the custom equation on another set of samples, after which the number of responses should increase, thus involving more listeners and finally improving the quality of the noise recordings in order to guarantee greater quality to the answers given by the listeners. Since the hood is an essential house appliance it would be interesting to estimate the effect of kitchen hoods noise on the speech intelligibility in the kitchen environment. The sound quality approach could be useful to define an alternative index for indoor acoustic comfort.

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