Modeling of human aggregations as noise sources in city noise mapping

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ABSTRACT

Noise mapping of urban areas requires an inventory of the various noise source categories which contribute to the acoustic environment, and their assessment by means of direct measurement and/or simulations. In the case of Venice old town, the absence of road traffic allows other contributions to emerge as relevant in determining overall noise levels: acoustic emission generated by human aggregations is one of these, which we tried to treat just like the ordinary ones. Unfortunately, neither common EU methods nor appropriate technical standards are available as a guide for modeling these sources. So, in order to evaluate their contribution, an attempt was made to implement ad hoc source models, based on linear and/or areal schemes. Specific acoustic power and spectral data were collected, by means of measurements performed in real situations, for incorporation into the acoustic model. In the end, using a suitable noise propagation software, maps of noise levels generated by the specific source were produced.

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1. INTRODUCTION

Noise mapping of urban areas requires an inventory of the various noise source categories which contribute to the acoustic environment, and their assessment by means of direct measurement and/or simulations (1,2).

In the case of Venice city area noise mapping, which we treated on the basis of a specific assignment by Venice Council, the mapping of Venice insular old town constitutes a special case: in fact, road traffic, which makes the most important contribution to noise level in other cities, is here almost completely absent. Nevertheless, Venice cannot be considered a silent city at all: canals are continuously swept by private and public motorized boats, and, on the other hand, thousands of vociferating people walk or stay at any time outdoors, along narrow alleys or in little squares. So, inside the noise mapping, in order to give a realistic representation of the exposure to environmental noise suffered by people living in Venice old town, we also need to evaluate the spatial and temporal distribution of noise levels generated by these noise sources. To do this for the entire territory of the town, we need to employ an appropriate simulation model, which means an appropriate propagation algorithm but, above all, a suitable scheme for source modeling with appropriate acoustic power and spectral input data to be assigned to the sources inside the simulation model.

In the following we describe how we dealt with the problem of source modeling in the case of human aggregations, for which neither common EU methods nor appropriate technical standards were available as a guide

2. HUMAN AGGREGATIONS AS NOISE SOURCES

2.1 Noise sources inside a human group

Humans can produce noise in several ways: speaking, crying, walking, moving objects such as chairs or cutlery. When many people gather spontaneously in a place for fun, the human voice is generally the prevalent source of acoustic emissions. Acoustic features of human voice such as loudness, spectrum, time modulation, can vary in a wide range from one individual to another; as much as a single individual can modulate his voice in a wide range of modes. Nevertheless, the greater the

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number of individuals gathered together, the more the features of the overall noise emitted by the aggregation tend to be homogeneous. On the basis of this hypothesis, supported by results of various on-field measurements, we attempted to identify simple rules, suitable for predicting the acoustic emission of such a human aggregation.

2.2 Characterizing noise features by on-field noise monitoring

Our institutional task includes checking various kinds of noise sources by direct noise monitoring. Among others, we often had the opportunity to monitor situations where different numbers of people gather outdoors for fun, such as on terraces of bars or restaurants, or in public spaces such as alleys or squares.

The results of some noise monitoring sessions, in terms of level time history and spectrogram, are shown in Figures 1 and 2, which are referred, respectively, to the terrace of a restaurant (20-30 people), and to a square with several terraces and also people standing in the public area (hundreds of individuals).

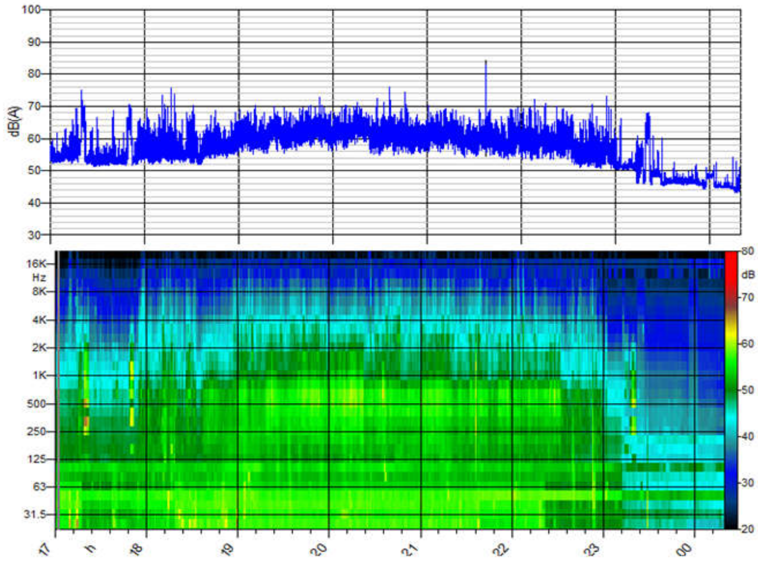

Figure 1 – Noise level monitoring - restaurant terrace (20-30 people)

Collecting this data we can observe some common features (3).

Loudness, in terms of overall noise level L_{Aeq}, depends, obviously, on the number of individuals (for the moment let us take this as qualitative evidence: not always was it known precisely).

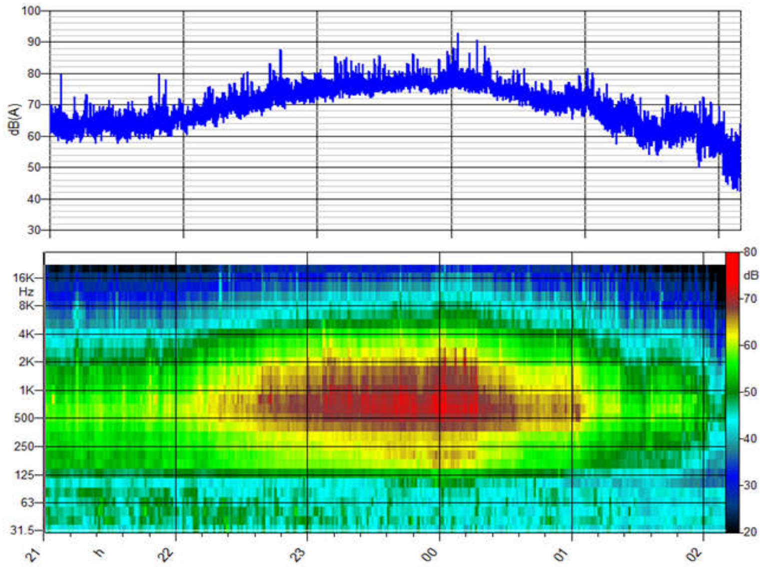

Figure 2 – Noise level monitoring – square with hundreds of people

Time modulation of the noise level also varies with the number of individuals; when this number is high, the noise level is nearly stable (or varies very slowly).

The noise spectrum shape is shown to be reproducible from one case to another, despite the wide range of different situations. Various results of measurements conducted in real situations show that the spectrum of multiple human voices speaking at the same time has a maximum value in the range between 500 and 2000 Hz, whereas the level drops at frequencies beneath 500 Hz

Other tests were performed in pedestrian streets with a high number of people passing through on foot. An example of the results of such kind of noise monitoring is shown in Figure 3.

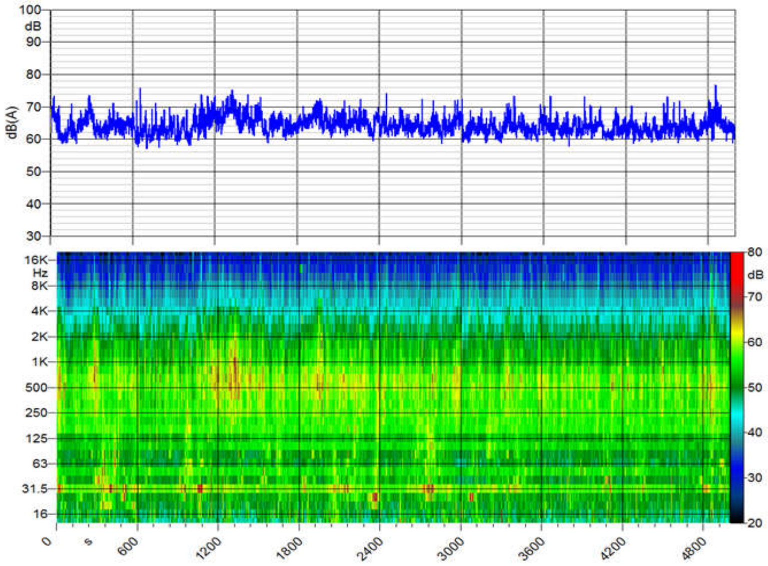

Figure 3 – Noise level monitoring – pedestrian street

In the case of people passing by, the spectrum shape we have repeatedly found is similar, but slightly different from that of people staying on a terrace: the maximum level is at 500 Hz, but at higher frequencies it diminishes more rapidly then the other. Perhaps, this might be due to the contribution by noise not originating from human voice, such as the noise produced by walking,

On the basis of these qualitative features, emerging from on-field tests, we considered the possibility of building up a scheme for modeling such noise sources in a general way. This means defining: the geometric model of the noise source (linear, areal or other) and its spatial extension; the shape of the spectrum; the elementary units of which the source is built up; and, finally, the acoustic power of such elementary units, from which the acoustic power of the entire source can be calculated.

2.3 Defining noise source modeling schemes

Relevant situations in which the simultaneous presence of a large number of people can be found outdoors are of two kinds: people who stay in a place, such as on external terraces of restaurants, pubs or spontaneously in public areas; or people who pass through along roads or lanes.

At first let us deal with the first kind of situation. In this case, the aggregation can be seen as an areal source, whose extension coincides with the area occupied by the terrace, or with the area spontaneously occupied by people. On a terrace, when full, individuals can be considered, as a first approximation, homogeneously distributed over the terrace surface; on the other hand, in the case of spontaneous aggregations, the extension of the source should be deduced by direct observation and, if necessary, the area should be divided into sub areas where the distribution of people is homogeneous.

Taking into account that the source of acoustic emission is concentrated in the mouth, the surface that constitutes the source must be put at a height of approximately 1 meter above the ground if the people are sitting (for example in a restaurant terrace) and at 1.5 meters if the people are standing.

Two parameters are necessary to characterize the source: the surface area S and the capacity, in terms of maximum number N of persons that can stay simultaneously inside the area of the source. We can then calculate the human concentration of the source in terms of number of persons per square meter. If we are able to determine the average acoustic power level L_{wo} of a single individual (in the hypothesis, which we can accept as a first approximation, that it has a constant value), we can then easily determine the acoustic power level per unit area L_{wS} of any source of this kind by the formula:

$$L_{wS} = L_{W0} + 10\log N - 10\log S \qquad (1)$$

L_{wS} can be used as input data for sound propagation models.

In the case of people who pass through, we might also adopt the scheme of areal source based on human concentration; human concentration can be calculated from the human flux (number of persons passing per time unit) and the average speed of passing people. Instead, we preferred to adopt in these cases a linear source scheme, analogous to those ordinarily implemented in the modeling of road traffic noise. As a matter of fact, the source is more similar to a line rather than a surface.

We determined the average acoustic power level per length unit of the street L_{w0L}, due to a single person transit per unit time (hour), from which the total power level per length unit L_{wL} of the source can be calculated, if the flux Q (number of transits per hour) is known, by the formula:

$$L_{wL} = L_{w0L} + 10\log Q \tag{2}$$

In the case of large streets, in order to take into account that people tend to walk over the whole width of the street, also very close to the noise level calculation points on the facades of buildings. To minimize the estimate errors we then distributed sound power over two, three, or more parallel line sources along the street.

In the case of people passing through, the linear source must be put at a height of approximately 1.5 meters above the ground,

As to the directivity of the emission, in both cases we supposed the sources to be isotropic. In reality, the sound emission of a single individual is highly directive, but when the individuals gathering in a place are numerous, they presumably will be randomly oriented, so, as a first approximation, the entire aggregation can be seen as an isotropic source, at least on the horizontal plane.

3. SOURCE POWER LEVEL AND SPECTRUM SHAPE

3.1 Areal sources

We made the hypothesis that the aggregated noise source was made up of a number of elementary sources consisting of single average speakers, each with equal power level and equal spectrum shape. In order to determine the acoustic power and spectrum shape of the elementary source, we needed to resort to measurements.

In the case of areal source, we tried to get a precise quantification of sound power by means of an inverse method (4). In a real situation (the terrace of a pub, with place for about 40 people), we measured noise levels in two points outside the terrace, during ordinary activity with the terrace full. We then extracted equivalent levels L for each octave band, having previously excluded every relevant noise event which had not originated from the people speaking on the terrace. The day after, when the pub was closed, we made an additional series of measurements in the same two points, generating acoustic emission by means of a pink noise source of known acoustic power $L_{wsource}$, instead of the real source. Such a source was placed inside the terrace, moving it in sequence to the points of a regular grid, which covered the entire extension of the terrace, as to approximate the continuous areal source. For each of the n positions (i) of the grid, measurements of the sound level l_i at the receptor points were performed. We could then determine with equation (3) the transfer function Tr, in dB, from the acoustic power of the entire areal source of the terrace to noise levels at each of the two receptor points.

$$Tr = 10\log\left(\sum_i 10^{l_i/10}\right) - \left(L_{wsource} + 10\log n\right) \tag{3}$$

Knowing the transfer function, we could easily determine the spectral sound power levels of the real source, by applying it inversely, for each of the two receptor points, to the noise levels L resulting from the measurements made in the real situation, with the terrace full. Then, knowing the number N of people occupying the terrace at the time of our first series of measurements, with equation (4) we could determine the average spectral power level L_{w0} of the elementary source consisting of a single individual.

$$L_{w0} = L - Tr - 10\log N \tag{4}$$

This sequence of measurements was conducted at the level of octave frequency bands, in order to obtain also a suitable power spectrum shape. The calculation was performed separately for each of the two receptor points, and in the end the average value of the two was taken into account. The results are shown in Table 1.

Table 1 – Average individual power level spectrum L_{wo} for areal source, obtained from direct measurement

Octave frequency band	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Power level, dB	53.6	59.3	68.6	68.6	67.0	66.2

The corresponding overall individual average power level L_{wo} is 73.5 dB(A).

In the hypothesis that this data is reproducible in different situations (that means with different number of speakers, different extensions of the area, different concentration of people), it constitutes the basic data for calculating, via the formula (1), the sound power per square meter of every noise source of this kind, which is the basic input data we need for sound propagation software.

Some tests were conducted in other real situation to verify the consistency of the method: they showed that if the aggregation is not too numerous, the hypothesis of constancy of individual sound power level is confirmed (within the limits of measurement and simulation uncertainty); only if the number of people and their concentration are extremely high, the method underestimates the real noise level.

In the end, individual spectral sound power levels reported in Table 2 were set as basic input data for noise emission of areal sources in noise mapping.

3.2 Linear sources

In the case of linear sources, we adopted a different approach: we made some measurements in real situations in streets and alleys, with concomitant counting of human flux (n° of persons passing per time unit). The shape of the spectra derived from such measurements is shown in Figure 4.

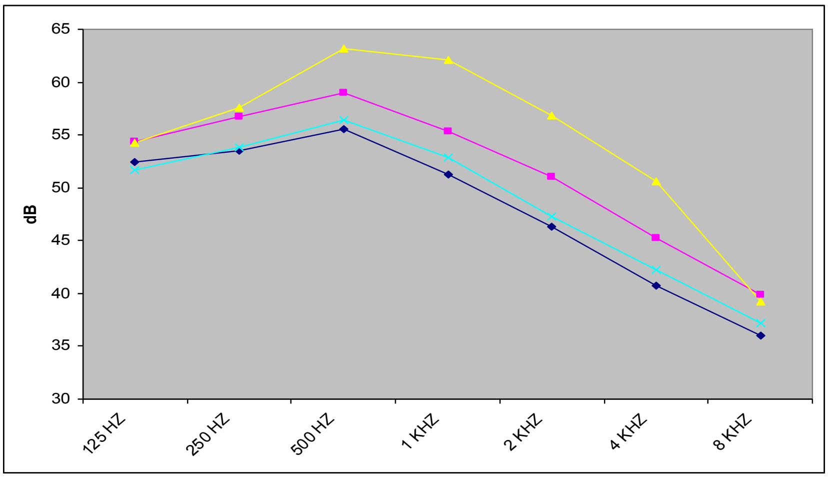

Figure 4 – Spectra revealed in streets with different fluxes, compared with spectrum of Table 1

They were obtained in three different streets, with different geometric features and with different human fluxes; their shapes are shown to be highly reproducible, despite the different situations (the yellow line represents, instead, the average individual power spectrum previously shown in Table 1, adopted for areal sources).

From this data we then obtained an average spectrum shape, and set it as standard spectrum shape input for noise mapping for linear sources. It is shown in Table 2.

Table 2 – Power level spectrum for linear source in dB, normalized at an overall level of 20 dB(A)

Octave frequency band	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Power level, dB	15.2	17.1	18.8	15.4	11.1	5.1

As said before, this spectrum shape is similar, but not equal to the spectrum we associated with human aggregations in the case of areal sources. We did not look into this difference, but we accepted it as a matter of fact.

In order to determine a power level as well, inside the noise simulation software we then created the linear source simulating the street where we had performed our measurements, to which we attributed the spectral shape shown above. We made the propagation software run, adjusting the power level per length and flux unit, until the result fitted the noise level resulting from the measurement: this procedure was repeated for various sites where such measurements had been done. In the case of a large street, the flux and the relative acoustic power was divided into parallel linear noise sources.

We then adopted, as standard elementary sound power level per unit length and flux, the overall average resulting from these repeated tests. It was L_{w0L} = 33.3 dB(A), referred to a length of 1 meter and to a flux of 1 transit per hour.

After spreading the above power level over the spectrum, in accordance with the shape shown in Table 2, for every homogeneous tract of street we could then calculate, with formula (2), the spectral sound power level L_{wL} per unit length to use as input for the linear source scheme in the simulation software.

4. IMPLEMENTATION OF THE SIMULATION MODEL FOR CITY NOISE MAPPING

On the basis of the acoustic data, obtained as described, we set up the acoustic propagation model: we used a commercial noise simulation software with propagation algorithms in compliance with ISO standard (5), and inside it we implemented the two kinds of noise sources. For the evaluation of noise levels produced by persons passing by, we created a geo-referred network (graph) of lines, corresponding to the main pedestrian paths in Venice old town (Figure 5). Each tract of the network was identified as a single line source, located at the center of the lane and 1.5 meters above the ground. The magnitude of the source, in terms of overall acoustic power per unit length, was obtained from the human flux data, that is the average number of individuals passing per hour.

Figure 5 – Graph of pedestrian paths in Venice old town

Flux data were obtained by direct counting, carried out in most of the main paths in the day-time (t_0).

In a restricted sample of places with high human flux, continuous noise monitoring was carried out for several days and nights. Average flux data $Q_i(T)$ for day, evening and night times (defined in accordance with EU standard), for every tract i of the network, was then extrapolated from direct counting data $Q_i(t_0)$ obtained at time t_0 for the specific tract, in accordance with the shape of noise level time history $L_m(T)$ obtained at the continuous monitoring point:

$$Q_i(T) = Q_i(t_0)10^{(L_m(T)-L_m(t_0))/10} \quad (5)$$

In the case of areal sources, Venice Council provided a database containing location, area and maximum authorized capacity of each external space, for which a concession had been granted. This database allowed us to create a set of geo-referred areal sources, each with the appropriate value of acoustic power per unit surface, derived, according to formula (1), on the basis of the standard data we had previously obtained.

In this case, too, average power levels per unit surface were calculated separately for day, evening and night time, on the basis of the opening schedule of each catering business. Unfortunately, this data was not complete, nor very accurate: first, data concerning spontaneous crowds forming outdoors, not connected to specific licence granting for use of external areas, were not included; second, the calculation is based on the non-realistic (but conservative) hypothesis that the terraces, when open, are always full. An appropriate scaling factor should have been applied to the authorized capacity of the terraces, in order to take into account this issue, but we were not able to find any feasible way to get reliable data, useful to quantify it. So, whereas for linear sources the results we achieved can be considered rather complete and realistic, for areal sources the mapping could not reach the same level of accuracy.

5. RESULTS

After running the simulation software, we obtained noise levels in terms of L_{Day}, $L_{Evening}$, L_{Night} and L_{DEN}, as defined in (1), over a regular grid of 1 meter step. The calculation was performed at the height of 4 meters above the ground, as required by European legislation. Examples of noise level maps are shown in Figures 6 and 7. In Figure 6 a noise level map in terms of L_{DEN} is shown, obtained by considering, as noise sources, pedestrian paths only (linear sources).

Figure 6 –Example of noise level map. Noise source: pedestrian paths only

In Figure 7, instead, we have added the contribution of areal sources as terraces of bars and restaurants.

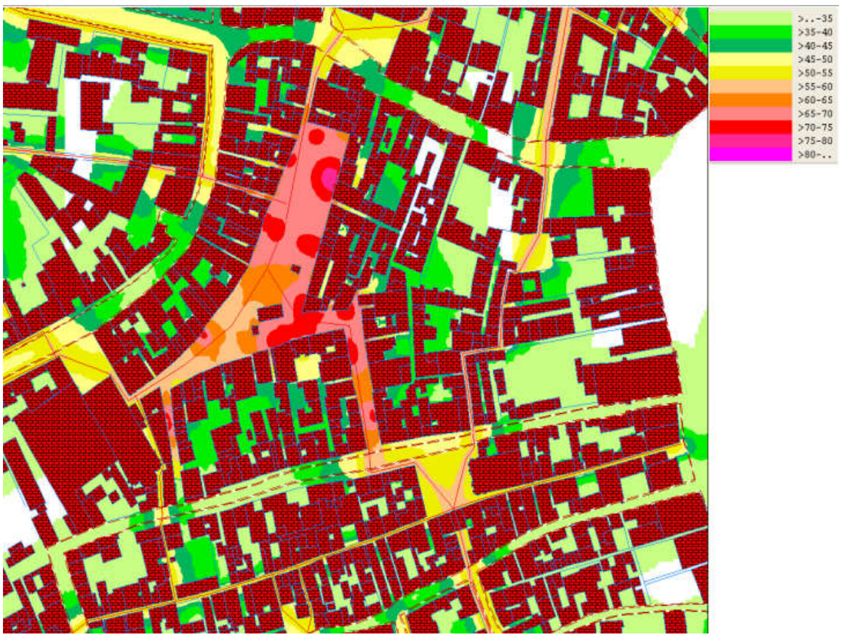

Figure 7 –Example of noise level map. Noise source: pedestrian paths and terraces

Adding, for each point of the grid, the contribution of these sources to those of all other sources, including water traffic, road traffic, railroad, port, we calculated the overall noise level maps.

Further, we calculated noise levels on the façade of each residential building; we could then identify the buildings exposed to noise levels exceeding the reference values specified by Italian law, and mark each of them on the basis of the size of the excess. An example of such a map of critical buildings, referred to L_{Night} , is shown in Figure 8. It can be seen that a part of the marked buildings lie on pedestrian streets or squares, where the most relevant noise source is human.

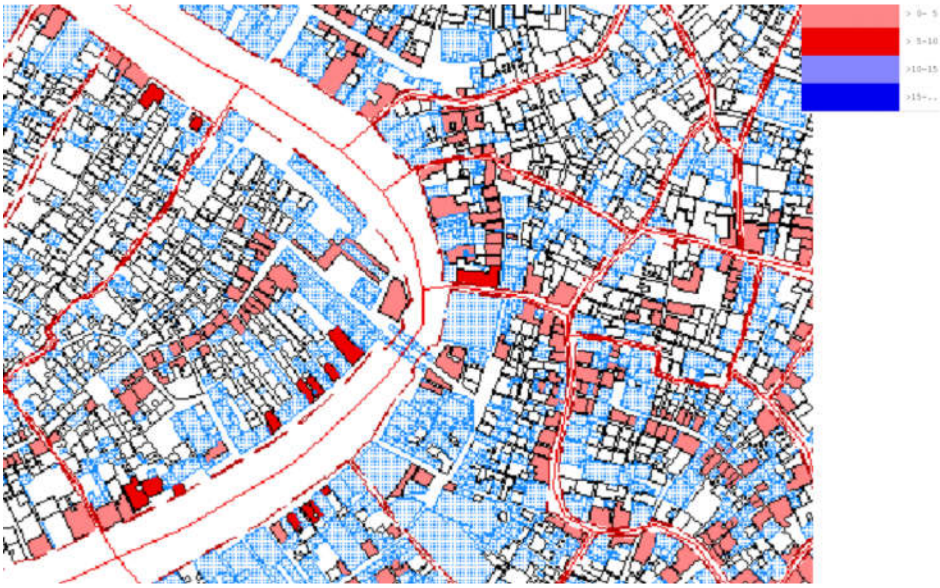

Figure 8 – Map of critical buildings for L_{night}

Finally, we were able to take into account the noise generated by human aggregations in the determination of the global percentage of resident individuals exposed to different noise level classes, which constitutes the basic exposure index for comparison among urban areas.

6. CONCLUSIONS

Several complaints submitted to authorities, confirmed by acoustic monitoring campaigns performed in various real situations in Venice, have shown that the simple presence of human aggregations can produce high sound levels, affecting residents' life environment.

We made an attempt to take into account this kind of noise source in city noise mapping, by means of simulations based on both linear and areal source schemes, and making use of input data derived by direct measurements. The method is to be improved, for example by analyzing the directivity of the sources, or the trend of individual average acoustic power for increasing values of people concentration. Nevertheless, such an attempt has allowed us to make the calculation of exposure indexes in the noise mapping of Venice urban area more complete and realistic.

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