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An experimental study on the audio-visual impact and integration of split system units on buildings façades

Masullo, Massimiliano
Maffei, Luigi
Pellegrino, Rossana
Department of Architecture and Industrial Design, Università degli Studi della Campania "Luigi Vanvitelli"
Abbazia di S. Lorenzo ad Septimum, Aversa (CE), Italy

ABSTRACT

Despite the complex, sometime mutable, political context, where agreements against climate changes have been signed by worldwide nations, and scientific and technological challenges to reduce GHG emissions and to increase the energy use produced by renewable sources were undertaken by HVAC industries, the demand of air conditioning systems for buildings' heating and cooling, is still increasing. Among the different room air conditioning systems, in Europe, split systems account for the majority of AC units with more than 30 million. In historical city centers, these types of ACs units have been often opposite due to their noise emissions and visual impacts on existing facades. These impacts are evaluated separately. Noise impact is assessed comparing the results obtained by outdoor noise prediction models with specific noise emission limits level at receivers. ACs visual impact is just relegated to local regulations. Virtual reality may supports performing multisensory studies to better understand actual combined impacts on residents, reproducing, ecologically, perceptual experiences.

The aim of this paper is to investigate on the combined, acoustic and visual, impact of the installations of external split units, on facades. Noise annoyance and other attributes of the perceived environment have been investigated combining noise and mimicry level of ACs.

Keywords: Noise annoyance, HVAC Impact, building integration
I-INCE Classification of Subject Number: 79

[1] massimiliano.masullo@unicampania.it
[2] luigi.maffei@unicampania.it
[3] rossana.pellegrino@unicampania.it

1. INTRODUCTION

Building sector is responsible of almost half of the energy consumption on a global scale [1]. Big part of this energy (about 40%) [2] is used by Heating, Ventilation and Air-Conditioning (HVAC) systems to maintain the optimal thermal conditions inside buildings and to ensure the comfort of occupants. For historical buildings, which represent about 30% of the total buildings European stock [3], most of the Best Available Technologies [4] set up for common buildings are not applicable, since they are in contrast with the conservation of their historical value [5]. For this reason, several authors which treated energy efficiency of cultural heritage have proposed procedures [6] or compared solutions, that consider suitable architectural/landscape integrations, e.g. *Becchio et al.* [7] compare architectural, energy and financial aspects of two refurbishment alternative scenarios; *Cabeza et al.* [8], classify different energy efficiency approaches and integration of renewable energies. Beyond these aspects, when buildings are close each other and road traffic is very weak, noise emitted by the HVACs is an additional issue to consider, as it can engender noise annoyance in neighbours.

Room Air Conditioners (RAC), such as the split-systems, are very common and easy to install. They account more than 30 million of units installed in EU [9]. However, in historical city centres, they are opposed by the inhabitants, for their noise emissions and visual impact on façades. Few authors have been in depth studied the effect of outdoor HVAC's noise on people. In one of them, *Breadly* [10] provided dose-response curves to derive acceptable levels for air conditioners noise. He also showed that noise annoyance doesn't depend only from the noise levels, e.g. owners of air conditioners were less disturbed to noise than from neighbours' air conditioners. On the other hands, HVAC's visual impact is just relegated to local regulations.

Recent interdisciplinary studies [11-13] have showed that, in multisensory experiences, auditory and visual stimuli interact each other, influencing the subjective responses, and that Immersive Virtual Environments can better simulate combinations of physical and human factors.

This paper investigates on the acoustic and visual impact caused by the installation of the external units of split systems on the façade of an historical building. To this aim, a laboratory experiment based on the use of Virtual Reality and a short questionnaire, has been prepared. Comparisons among subjective ratings toward auditory, visual and global aspects were carried out, at different noise levels and camouflage of the external units of air conditioners.

It is expected that, besides the improvement of the visual pleasantness, the use of covers that camouflage the external units of the air conditioners could influence the perception of HVAC noise and their general integration.

2. METHODOLOGY

The research is based on a subjective experiment conducted in laboratory by means of virtual reality. Starting from a basic virtual scenario the reproduces an urban context with an historic building, further scenarios have been created changing some visual and auditory characteristics. Visual changes concern of the installation of 2 external split units on the façade of the historical building. These units were virtually installed, without and with different camouflage covers. Auditory changes concern the combination of noise emitted at two functioning conditions of external split units with the urban background noise. In the virtual environment, the participants were positioned in front of the façade under investigation, at the balcony of the first floor. A short questionnaire of 4 questions has been administered to a group of participants to investigate on the audio and visual impact and integration of split systems on buildings façades.

2.1 Experimental design

Two main factors were considered in the experiments: the *noise level* (L) and the *visual aspect* (V). The *noise level* had 2 levels: steady condition (L1) and starting condition (L2). The *visual aspect* had 4 levels: No cover (V0), Classic cover (VC), Paint cover (VP) and Geometrical cover (VG). Moreover, an additional control scenario (CTRL) without the external air conditioning units installed on façade (V0) and with only background noise (L0) has been implemented. To observe the possible interactions among the visual and auditory factors a 2×4 within factorial design + 1 (CTRL) was scheduled for the experiment. Four dependent variables: *Loudness*, *Noise Annoyance*, *Visual Pleasantness* and *Integration*; have been selected to investigate if auditory, visual and global aspects can be influenced by the noise level and visual aspect.

2.2 Audio-Visual Material

A 3D model has been built and implemented in a game engine. The model consists of an urban street portion with different buildings, included an historical building which is object in our study (Figure 1). The architectural characteristics and colors of the historical building have been selected according to existing rules of municipalities of some Italian historical centres [14-18].

Figure 1 – Left: Overview of the scene; Right: Facade of the historical building.

Two external air conditioners have been virtually installed on the facade of the historical building (Figure 2). To investigate the impact of the external air conditioning units and their integration level on the facade they were modelled with 4 different visual aspects (Figure 3):

- V0, the external air conditioning unit was a traditional white box;
- VC, the external air conditioning unit was masked with a classical style cover;
- VP, the external split unit was masked with a painted cover as the façade frames;
- VG, the external split unit was masked with a cover with a geometrical style.

Figure 2 – Receiver POV of the 2 external air conditioners (V0) on the building façade.

Two different types of audio recordings have been done: the background noise at receiver, and the noise emission at source. The first was recorded at a balcony of an urban pedestrian zone and the second at 1 m from an external split unit of 3.5 kW. The latter recording was carried out during two functioning modalities: *starting* and *operating condition*. The noise levels recorded at the source were about 60 dB(A) in *starting condition* and 58 dB(A) in *operating condition* while the background noise at the receiver was about 48 dB(A). These recordings were positioned, as ambient sound objects in the software Unreal Engine 4 (UE4): the background noise at the receiver and the HVAC noise at 1 meter in front the external units of air conditioners. The sound propagation effects (spherical spreading, air absorption) up to the receiver were implemented in the virtual reality model by the middleware Wwise [19]. The audio playback chain (PC + sound card + headphones) has been calibrated by a Mk1 Cortex dummy head and a 2-channel sound card Symphonie. The measured A-weighted sound equivalent levels at receiver were about: 48 dB(A) (L0), 50 dB(A) (L1), 52 dB(A) (L2).

Figure 3 – External air conditioners with cover: Left: VC; Centre: VP and Right: VG.

2.3 Questionnaire

A short questionnaire has been prepared (in Italian language) and administered to the participants to investigate how they evaluate the impact of the air conditioning units on the building façade. The Questionnaire consists of an introductive main sentence and 4 questions on Auditory, Visual and Global aspects: *Loudness* and *Noise Annoyance*; *Visual Pleasantness*; *Integration*, to which the subjects answered on a 7-points Likert scale from: Not at all (1) to Extremely (7). The English translation is showed below:
Main sentence: "*You are on the balcony of your apartment to take a breath of fresh air. Seeing the building in front of you, ...*";
Questions:
- *How much loud you consider the environmental noise of this place*?
- *How much annoying you consider the environmental noise of this place?*
- *How much visually pleasant you consider the building façade?*
- *How much you rate the integration of the elements on façade?*

3. TEST PROCEDURE

Before to start the experimental session, to each participant was asked to read the privacy policy and to consent the processing of personal data. Then they provide their general information and fulfil a questionnaire on noise sensitivity. Afterwards they had a brief introduction to the experiment and they were invited in the anechoic room of the Department of Architecture and Industrial Design, to sit on a chair and to wear a Head Mounted Display HMD Oculus Rift DK2 and Pioneer SE-MJ722T-R headphones.

Then the participants explored the virtual environment and were invited to simulate the answering of the four questions. Once the procedure was clear, to each subject, 9 different audio-visual scenarios were administered in a random order. Each of them was presented for about 2 minutes. After the first 30s the participants could answer to the 4 questions filling out a short questionnaire. The entire session lasted about 25 min. This preliminary experiment has involved 15 participants (6 Female) aged between 18 and 39 years.

4. RESULTS

To investigate preliminarily if noise levels and the visual aspect of the scenarios can influence the perception of *Loudness*, *Noise Annoyance*, *Visual Pleasantness* and the *Integration*, the score differences "Scenario - CTRL" were analysed by two different sets of ANOVAs: at the *noise level* L1 and L2. Each ANOVAs' set treated Scenarios as four-level within-subjects factor (V0L1, VCL1, VPL1, VGL1; V0L2, VCL2, VPL2, VGL2).

As regard the *Loudness*, results show that the *Visual aspect* has a tendency to have a significant effect at L2, $F(3,42)=2.724$, $p = 0.056$. The greatest increasing of *Loudness* was appreciated when the external units of air conditioners were without covers ($M_{V0L2} = 2.80$). The lowest when classic and the geometrical covers ($M_{VCL2} = M_{VGL2} = 1.86$) were used (see Figure 4 left). No significant effect has emerged at L1.

Results on *Noise Annoyance* show that *Visual aspect* has a significant effect at L2, $F(3,42)=3.538$, $p < 0.05$. The highest *Noise Annoyance* increases occurred without covers and with the painted cover, ($M_{V0L2} = M_{VPL2} = 2.73$) (see Figure 4 right).

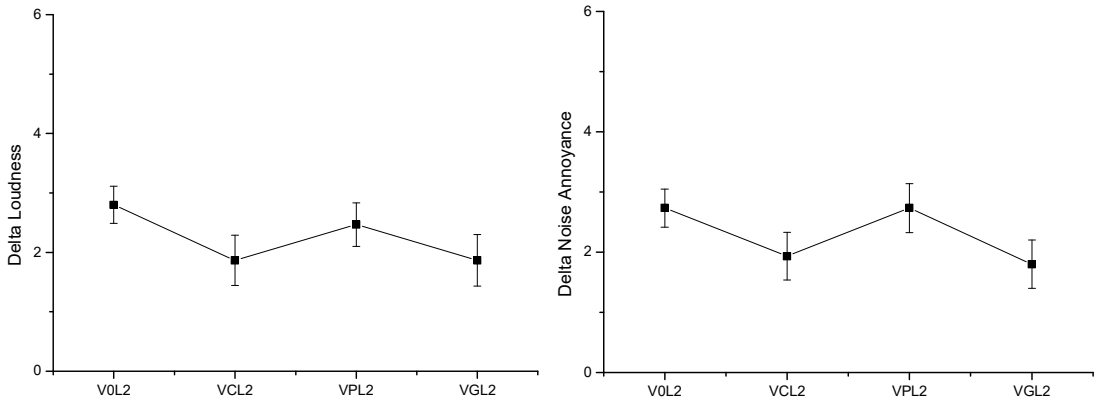

Figure 4 – Increase in Loudness (left) and Noise Annoyance (right) at level L2, compared to CTRL scenario.

When the noise level is L2, the *Visual aspect* has also a significant effect on the *Visual Pleasantness* decrease: $F(3,42) = 3.629$, $p < 0.05$. Means comparison reveal that the greatest decrease occurs when the external units are installed without cover, ($M_{V0L2} = -2.53$). The lowest decrease when on the external air conditioners were used geometrical cover, ($M_{VGL2} = -1.00$). Despite the scenario without cover cause the greatest decreasing of *Visual Pleasantness* (Figure 5) ($M_{V0L2} = -2.60$). No significant has been observed at L1.

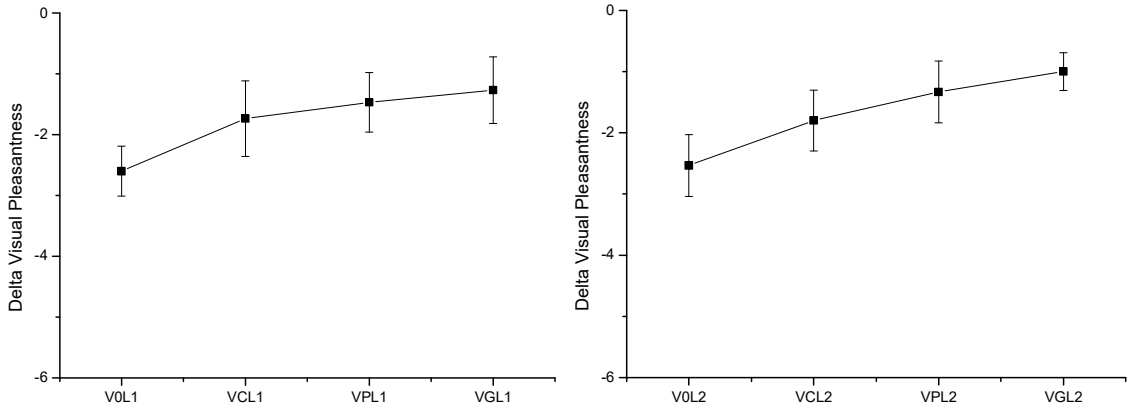

Figure 5 – Decrease in Visual Pleasantness at L1 (left) and at L2 (right), compared to CTRL scenario.

As regard the *Integration*, results show that the Visual aspect has a significant effect at the level L1: $F(3,42) = 7.959$, $p < 0.001$, and L2: $F(3,42) = 5.142$, $p < 0.01$. Means comparison reveal that the greatest decrease of integration occurs when external units of air conditioning were installed without covers ($M_{V0L1} = -3.20$) and ($M_{V0L2} = -2.70$).

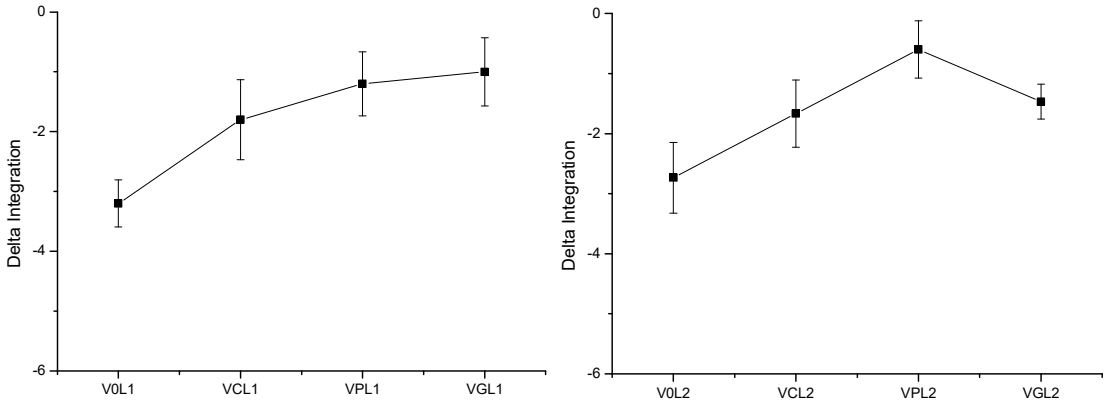

Figure 6 – Decrease in Integration at L1 (left) and at L2 (right), compared to CTRL scenario.

5. CONCLUSIONS

The paper deals preliminarily on the audio and visual impact and integration of the external units of air conditioners on historical buildings façades. To this aim, in a laboratory experiment that uses the Virtual Reality, four different perceptual attributes have been investigated: *Loudness*, *Noise Annoyance*, *Visual Pleasantness* and *Integration*, modifying the *Noise Level* and the *Visual Aspect*.

As expected, ratings of participants show that the installation of the external units on the façade of the historical building led to an increasing of the sound levels, and then of the *Loudness* and *Noise Annoyance*, and to a decreasing of the *Visual Pleasantness* of the building facade and of the perception of the *Integration*.

The statistical analyses of this preliminary study shows that the visual aspect of the Scenario have a slight moderator effect on the Loudness and the Noise Annoyance of participants. However, these effects have emerged only at the higher level of the auditory stimulus, L2, while were absent at L1. On the other hands the *Visual Pleasantness* is strongly influenced by the presence and typologies of cover, as well as the *Integration* of the elements on façade.

Despite the encouraging preliminary results on the interactions between the Noise levels and Visual aspect of the external units of air conditioners, further experiments should be carried out to increase the number of participants and the reliability of the results.

6. REFERENCES

1. L. Schibuola, M. Scarpa, C. Tambani, *"Innovative tecnologies for energy retrofit of historic buildings: An experimental validation"*, Journal of Cultural Heritage, 30 (2018), 147-154;

2. J. Jazaeri, R. L. Gordon, T. Alpcan, *"Influence of building envelopes, climates, and occupancy patterns on residential HVAC demand"*, Journal of Building Eng. 22 (2019), 33-47;

3. M. Economidou. Energy performance requirements for buildings in Europe. REHVA Journal J. 2012 (3) 16–21;

4. EU Directive 1996/61 of the European Council concerning integrated pollution prevention and control. Off. J. Eur. Communities. L257, 10/10/1996;
5. D. Milone, G. Peria, S. Pitruzzella, G. Rizzo, *"Are the Best Available Technologies the only viable for energy interventions in historical buildings?",* Energy and Buildings 95 (2015) 39–46;
6. L. de Santoli, "*Reprint of "Guidelines on energy efficiency of cultural heritage"*", Energy and Buildings 95 (2015) 2–8;
7. C. Becchio, S. P. Corgnati, G. Spigliantini, *"Evaluation of refurbishment alternatives for an Italian vernacular building considering architectural heritage, energy efficiency and costs"*, Energy Procedia, 133 (2017), 401-411;
8. L. F. Cabeza, A. de Gracia, A. L. Pisello, *"Integration of renewable tecnologies in historical and heritage buildings: A review"*, Energy & Buildings, 177 (2018), 96-111;
9. S. Pezzutto, M. De Felice, R. Fazeli, L. Kranzl, S. Zambotti, "*Status Quo of the Air-Conditioning Market in Europe: Assessment of the Building Stock*", Energies, 10, (2017), 1253 (17 p);
10. J. S. Breadly, *"Disturbance caused by residential air conditioner noise"*, The Journal of the Acoustical Society of America, 93/978 (1993);
11. L. Jiang, M. Masullo, L. Maffei, "*Effect of odour on multisensory environmental evaluations: a case of using road traffic as source of environmental intrusions*", Environmental Impact Assessment Review. 60, (2016), 126-133
12. L. Maffei, T. Iachini, M. Masullo, F. Aletta, F. Sorrentino, V. P. Senese, F. Ruotolo, "*The effects of vision-related aspects on noise perception for wind turbines in quiet areas*", Int. Journal of Environmental Research and Public Health, 10(5), (2013);
13. M. Masullo, A. Pascale, L. Maffei, "*Effects of combinations of water sounds and visual elements on the road traffic noise mitigation in urban green parks*" Internoise 2016, Hamburg (Germany), 21-24 August (2016);
14. R. Frare, F. Semenzato, *"I colori della città del Giorgione"*, Comune di Castelfranco Veneto, Piano del Colore, (2008);
15. D. Marmorino, M. Petrucciani, *"Mappa cromatica di uno spazio urbano"*, Comune di Contrada, Piano del Colore, (2017);
16. E. Gottardello, S. L. Mantica, *"Piano del Colore per il centro storico della città di Crescentino"*, Città di Crescentino, Piano del Colore, (2007);
17. S. Putortì, A. M. Cassalia, F. Benincasa, F. Spinelli, D. Monteleone, *"Piano del colore e del decoro Urbano"*, Comune di Reggio Calabria, Piano del colore;
18. G. Brino, "Il piano del colore di Saluzzo", Comune di Saluzzo, Piano del Colore.
19. https://www.audiokinetic.com/ (last access: 25 February 2019).