Evaluation and improvement of the acoustic comfort in nursing homes: a case study in Flanders, Belgium

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Summary
In nursing homes, poor acoustic quality of living spaces might have an adverse impact on the behaviour and well-being of both residents and staff, decreasing their everyday quality of life. In the context of the AcustiCare project on the characterization and improvement of the acoustic comfort in nursing homes and the introduction of soundscapes in healthcare for older people, five nursing homes in Flanders (Belgium) were evaluated from the acoustical point of view. Correcting interventions were implemented, where possible. The evaluation of the acoustic comfort was two-fold: (1) sound levels in bedrooms and living rooms were monitored during a one-week period to get insights into typical temporal patterns; (2) the building acoustics of bedrooms, corridors and living rooms was investigated in terms of standardized level difference (D_{nT}), standardized impact sound pressure level (L'_{nT}) and reverberation time (T_{20}). Results for the sound level monitoring indicate that overall sound pressure levels are significantly different between the nursing homes, and daily patterns are observable for different types of spaces in the facilities. Regarding the building acoustics, high reverberation times in living rooms and poor sound insulation from living rooms and corridors to bedrooms were generally observed. In the second part of this study, different acoustic interventions were applied to reduce the reverberation time of the living rooms, as well as the sound propagation to bedrooms. The achieved improvements are presented and discussed.

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1. Introduction

The acoustic environments of care facilities are receiving increasing attention from both researchers and practitioners of the built environment, because of the importance that ageing-related issues are gaining in our societies. Previous studies have focused both on the perception [1, 2], as well as physical aspects of the acoustic environment of such spaces [3]. Acoustics is crucial to define the everyday experience of nursing homes [4], both for the residents and the staff members, due to the considerable amount of time they spend in these environments [5].

This study is part of the AcustiCare project [6], which aims at improving the acoustic environment in nursing homes, particularly for residents with dementia, and ultimately at providing architects and decision makers with a broad range of possible acoustic solutions for the organization and optimization of new or existing nursing homes.

The paper provides an overview of the acoustical situation of typical nursing homes in Flanders, Belgium. On one hand, sound levels were monitored during a one-week period to get an indication of typical noises related to residents and staff members in living rooms, bedrooms and corridors. On the other hand, the acoustic performance of the facilities was investigated in terms of standardized level difference (D_{nT}), standardized impact sound pressure level (L'_{nT}) and reverberation time (T_{20}).

After the acoustic characterization of the nursing homes, a number of in situ acoustic interventions were discussed and agreed with the company partners of the project, the staff members and the directors of

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the nursing homes [7]. Consequently, a second round of assessment was performed after the implementation of the agreed corrections. The performance of these acoustic interventions was measured in terms of building performance parameters, and their effect on noise levels was investigated again through a one-week sound level monitoring. Preliminary results illustrate the effect of the proposed measures on the overall acoustic environments of the facilities.

2. Acoustic environment of nursing homes: current situation

For the evaluation of the current acoustic environment, five different nursing homes were selected (in the text abbreviated as 'LH', 'SJ', 'SV', 'SP' and 'VH'), geographically spread over Flanders, Belgium. The selection consisted of a mix of both recently built facilities as well as (renovated) facilities dating from the end of the 20^{th} century. Of main interest is the acoustic environment in the resident's rooms and living rooms (and propagation between both).

2.1. Typical sound pressure levels

One of the aims of the AcustiCare project is characterizing the overall acoustic environment of everyday life spaces in nursing homes. For this purpose, cost-effective sensor nodes were installed in the nursing homes to monitor noise levels. Three types of spaces were considered: corridors (i.e. transition and functional spaces, as well as junction spaces between these and the living rooms), living rooms (i.e. common areas where groups of residents spend most of their day time and often have lunches in) and resident's rooms (i.e. individual rooms where residents stay alone or in couple, typically connected to the living rooms by corridors). Fifteen nodes were considered for this study (i.e. five nodes for each type of space) in the five nursing homes (i.e. three nodes in each nursing home). The nodes were installed at a distance from specific noise sources (e.g. telephone, washing machine, etc.), which could result in a distorted picture of the noise levels, but close enough to be representative of the activities typically taking place in such spaces. The nodes measured 1/3-octave band levels continuously (125ms temporal resolution). The monitoring intervals considered were from 07:00am of a Monday to 07:00am of a Friday, during a typical week of activity in the nursing homes, between December 2016 and February 2017. Data were sent over the internet to the Ghent University server infrastructure. The A-weighted equivalent sound levels were then calculated on a 15-minute basis (LAeq-15min) for the reference intervals, for each sensor node [5, 8]. The A-weighted equivalent sound levels were then averaged according to the types of spaces and to the nursing homes.

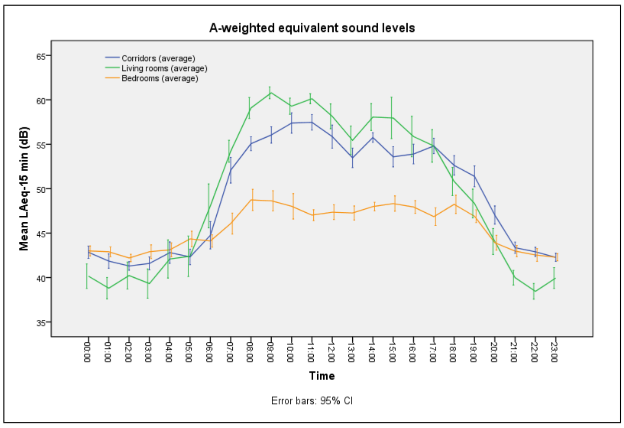


Figure 1. Daily patterns of the sound levels, according to the different types of space.

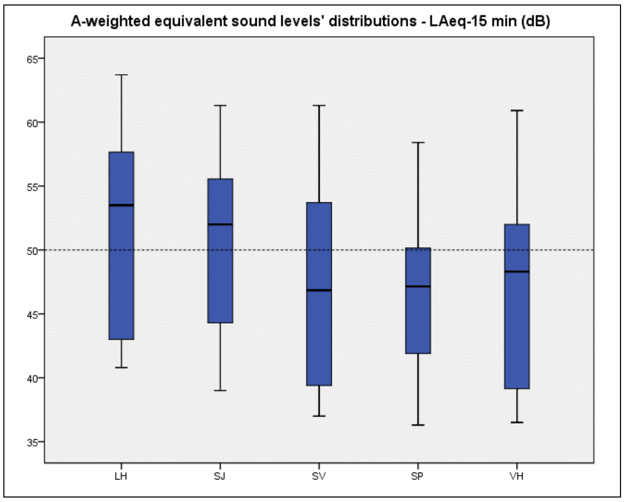


Figure 2. Distributions of the sound levels in the five nursing homes of the project, aggregated over time and space. The median levels are represented by the black ticks in the boxes, indicating the 2^{nd} and 3^{rd} quartiles.

Fig. 1 shows the sound levels as a function of time, aggregated for nursing homes and days of monitoring. In terms of daily pattern it can be observed that during the nights, levels are higher in the bedrooms and lower in the corridors and the living rooms: bedrooms are indeed occupied, living rooms are empty and there could be some staff occasionally moving in the corridors (e.g. night shift, care to residents). For most parts of the day, the levels in the bedrooms are lower because residents (and staff) are typically present in the living rooms; the levels of the corridors are lower than the living rooms, but follow more or less the same pattern because those spaces are often connected. After dinner, the levels in the living rooms drop because residents go back to their bedrooms and there is more activity in the corridors because of the shift-change, staff preparing for the night and pre-evening visitors.

In Fig. 2, data are presented according to the nursing homes, aggregated for times and types of space. It can be observed that two nursing homes are slightly 'noisier' than the others: these facilities have median levels ranging between 50dB(A) and 55dB(A), while the others have median levels ranging between 45dB(A) and 50dB(A) instead. Such differences depend on the specific sound sources that are present in each nursing home and possibly different behaviours of staff and residents.

2.2. Building acoustic performance

For the characterization of the building acoustic performance of the different nursing homes, a measurement campaign was organized with the aid of different acoustic consultants (project partners [7]). The airborne sound insulation was measured in terms of the standardized level difference D_{nT} [9], between living room and resident's rooms (5 cases), between corridor and resident's rooms (12 cases), and between resident's rooms (15 cases for rooms on the same floor and 3 cases for rooms vertically stacked).

The impact sound insulation (in terms of the standardized impact sound pressure level L'_{nT} [10]) was measured from living room to resident's rooms (3 cases), from corridor to resident's rooms (9 cases) and between resident's rooms (12 cases for rooms on the same floor and 3 cases for rooms vertically stacked).

In addition to these measures, which mainly describe sound transmission and propagation through building elements, the reverberation time T_{20} was measured as an indication for the acoustic comfort inside the room. T_{20} values were determined according to [11] in 17 different resident's rooms, 11 living rooms and 4 corridors.

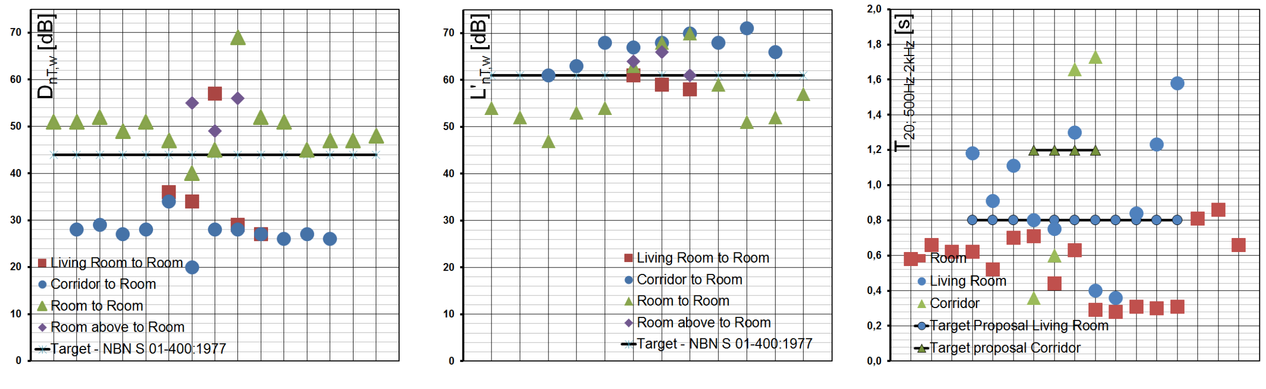
To enable rating based on a single-value parameter, D_{nT} and L'_{nT} 1/3-octave band spectra are converted to their weighted equivalent, $D_{nT,w}(C, C_{tr})$ and $L'_{nT,w}(C_i)$ [12, 13], while $T_{20;500Hz-2kHz}$, the average value of the reverberation time at the 500Hz to 2kHz octave bands, is used as a performance indicator for the reverberation time.

A summary of the results is given in Fig. 3 and average values with standard deviations are given in Table I and Table II. The Belgian target values are indicated as well and are stated as $D_{nT,w} > 44$dB and $L'_{nT,w} < 61$dB. These target values, defined by [14], are currently under revision and it is in agreement that these should be interpreted as minimal target values for normal acoustic comfort. The target value $T_{20;500Hz-2kHz} = 0.8$s for living rooms and $T_{20;500Hz-2kHz} = 1.2$s for corridors is based on values proposed in [15].

From Fig. 3(a) we see that the target value of $D_{nT,w} = 44$dB is fairly met for airborne sound insulation between resident's rooms, with $D_{nT,w} = 49.7$dB on average. In one case the condition is not met due to an acoustic leak originating from the heating pipe system. In contrast to this, the target for the airborne sound insulation between corridor and resident's rooms is not met. In this case, $D_{nT,w} = 27.3$dB on average. Here, the acoustic performance is mainly determined by the doors, which in most cases have ventilation slits at the bottom and bad acoustic sealing at the sides. The airborne sound insulation between living rooms and resident's rooms depends on the relative location between living room and resident's room. If the living room is a self-contained entity, with doors blocking soundpropagation to the corridor, performance similar as between resident's rooms is met. However, if the living room has an open structure, directly connected to the corridor, without any intermediate doors to block propagation, a performance similar as from corridor to resident's room is seen. In our study, the latter has been most often encountered.

Results for $L'_{nT,w}$ are shown in Fig. 3(b). In most cases the impact sound insulation between resident's rooms on the same floor complies with the proposed standard, $L'_{nT,w} = 56.7$dB on average. Nevertheless, impact sound insulation for vertically stacked rooms did not meet the target proposal. However, general conclusions should be drawn carefully as only three cases were investigated. Regarding the impact sound insulation from corridor to resident's rooms, measured values were higher than the proposed value in almost every case. On average, we measured $L'_{nT,w} = 66.9$dB. It should be noted that measurements in this case are not only determined by the performance of the impact sound insulation of the floor, but also by an airborne contribution from the tapping machine due to low D_{nT}-values. The impact sound insulation from living rooms to resident's rooms was measured in three cases. All cases complied with the proposed target value.

In Fig. 3(c) the reverberation time $T_{20;500Hz-2kHz}$ is given. For resident's rooms, no target value is given by the Belgian standard, as the room acoustics is mainly determined by the furnishing of the room. However, from measurements in 17 resident's rooms, an average $T_{20;500Hz-2kHz} = 0.55$s is found. $T_{20;500Hz-2kHz}$ is lower than 0.8s in almost every room. No such conclusions can be drawn for $T_{20;500Hz-2kHz}$, measured in living rooms. In most of the cases the target value is not met, and although the average $T_{20;500Hz-2kHz} = 0.95$s, a large standard deviation of 0.36s is seen, indicating that large differences occur. Lowest values were measured at the smallest living rooms (with absorption present), while highest values were measured in large living rooms with limited absorption. Additionally, measurements of $T_{20;500Hz-2kHz}$ were performed in four corridors. For two corridors results are below the target value of 1.2s. However, in two other corridors, with acoustically hard materials, this target value is exceeded, and values up to 1.83s were measured.



(a) $D_{nT,w}$ (b) $L'_{nT,w}$ (c) $T_{20;500Hz-2kHz}$

Figure 3. Building acoustic performance measured in five nursing homes.

Table I. Average acoustic performance in nursing homes. Mean values and standard deviations of $D_{nT,w}(C, C_{tr})$ and $L'_{nT,w}(C_i)$ are given.

	$\mu_{D_{nT,w}}(\mu_C,\mu_{C_{tr}})$	$\sigma_{D_{nT,w}}$	$\mu_{L'_{nT,w}}(\mu_{C_i})$	$\sigma_{L'_{nT,w}}$
Resident's room to room (same floor)	49.7(-1.3;-4.3)dB	6.3dB	56.7(-6.6)dB	6.8dB
Resident's room to room (different floor)	53.3(-1.0;-5.3)dB	3.8dB	63.7(-3.3)dB	2.1dB
Corridor to resident's room	27.3(-0.8;-0.3)dB	3.0dB	66.9(-9.2)dB	3.0dB
Living room to resident's room	36.6(-1.2;-1.2)dB	12.0dB	59.3(-10.7)dB	1.2dB

Table II. Average acoustic performance in nursing homes. Mean values and standard deviation of $T_{20;500Hz-2kHz}$ are given.

	$\mu_{T_{20;500Hz-2kHz}}$	$\sigma_{T_{20;500Hz-2kHz}}$
Resident's rooms	0.55s	0.19s
Corridors	1.09s	0.71s
Living rooms	0.95s	0.36s

3. Improving the acoustic comfort

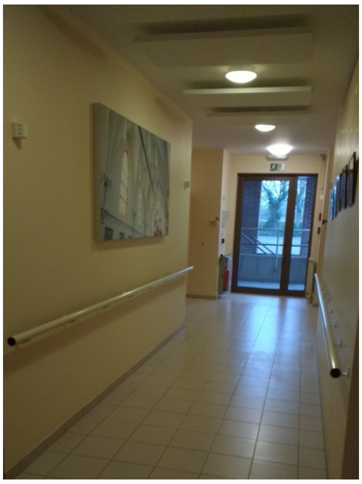
From each of the five nursing homes, a specific case was selected where an acoustic intervention was made by one or more of the project partners [7]. An overview of the different interventions is given in Fig. 4 and Fig. 5. In most cases it was opted to improve the situation with the worst acoustic performance. However, it was not the intention to cure all situations with low-quality acoustic performance, but rather to demonstrate a variety of different acoustic solutions to the participating nursing homes of the project. Interventions focused on (1) improving the building performance (reducing noise propagation to resident's rooms) and (2) improving the acoustic climate by reduction of the reverberation time. An overview of the achieved results are summarized in Table III.

When reducing the noise propagation to resident's rooms, we focused on acoustic interventions which reduce the sound propagation from living room and corridor to resident's rooms, rather than between resident's rooms, since previous results show that in most cases (airborne) sound insulation between resident's rooms already complies with the targets defined in standards. First, two interventions that directly improve the sound insulation problem originating from acoustic leaks by the doors were installed. In SV acoustic curtains of ShowTeX [7] were installed near the entrance of the resident's room, creating a small ante-chamber as an extra buffer between the corridor and the resident's room (Fig. 4(a)). Installation of this curtain improved the $D_{nT,w}$-value with 11dB. In LH, a large ventilation grill in the door of a resident's room was replaced by an acoustic ventilation grill by DOX-Acoustics [7] and absorbing panels (Gyproc [7]) were installed in the corridor leading to the entrance of the room (Fig. 4(b)), accounting for an extra 5dB increase of $D_{nT,w}$ between corridor and room. Secondly, interventions were taken to reduce propagation (of noise from living rooms) through corridors to resident's rooms. In SJ absorbing panels were installed by DOX-Acoustics on the walls (2m^2) and ceiling (four panels, 2.88m^2 in total) of the 12m-long corridor (Fig. 4(d)), not only reducing reverberation time $T_{20;500Hz-2kHz}$, but also reducing the propagation of noise by 2.5dB(A) on average. In SP, five absorbing panels of Triplaco [7] (5x 5.63m^2) were installed along a 26.5m-long

(a) Acoustic curtain (ShowTeX) in a resident's room (SV).

(b) Acoustic ventilation grill (DOX-Acoustics) and absorbing wall panels (Gyproc) (LH).

(c) Corridor with absorbing wall panels (Triplaco) (SP).

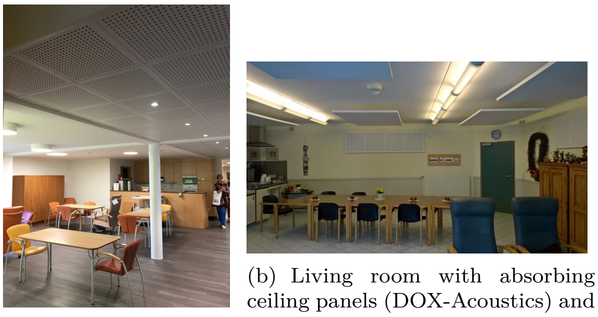


(d) Corridor with absorbing wall and ceiling panels (DOX-Acoustics) (SJ).

Figure 4. Overview of the acoustic interventions in resident's rooms and corridors.

corridor connecting resident's rooms with a living room at each side of the corridor (Fig. 4(c)). Aside from the reduction of $T_{20;500Hz-2kHz}$, an additional decay of 3dB(A) was achieved at the end of the corridor. Thirdly, interventions were taken to reduce generation of noise in living rooms and propagation to nearby resident's rooms. As an illustration on how to improve the impact sound insulation, an acoustic floating floor was installed in VH, on top of the floor of a living room and corridor nearing a resident's room (Fig. 5(a)). A reduction of $L'_{nT,w}$ with 12dB was achieved. In the same area covered with the acoustic floor, absorbing ceilings (Gyproc) were also installed. The main effect of this intervention was seen for the reverberation time, but the improvement of the $D_{nT,w}$ between the living room and the resident's rooms was negligible.

For the improvement of the acoustic climate, i.e. the reverberation time, focus was put on the living rooms (target value for $T_{20;500Hz-2kHz} = 0.8$s) and corridors (target value for $T_{20;500Hz-2kHz} = 1.2$s). For resident's rooms previous measurements typically showed acceptable values for $T_{20;500Hz-2kHz}$ (0.55s on average) and therefore little correction is needed. In VH a living room (consisting of two parts - a dining area and seating area) with a hard plaster ceiling was equipped with 110m^2 of acoustic gypsum tiles from Gyproc (in addition to the acoustic floating floor) (Fig. 5(a)). In the dining area a reduction of $T_{20;500Hz-2kHz}$ from 1.18s to 0.91s was achieved - still slightly higher than the target value of 0.8s, while in the seating area a reduction from 0.91s to 0.39s was obtained. A second living room in LH was treated with six absorbing ceiling panels by DOX-Acoustics (14.4m^2 in total) and 1.44m^2 of absorbing wall elements of Gyproc (Fig. 5(b)). Here, a reduction of $T_{20;500Hz-2kHz}$ from 1.3s to 0.57s was found. Furthermore, two corridors, one in SJ (absorbing panels were installed by DOX-Acoustics) and one in SP (five absorbing panels of Triplaco) have been selected for improvements (see above). In SJ the reverberation time was reduced from $T_{20;500Hz-2kHz} = 1.66$s to $T_{20;500Hz-2kHz} = 0.97$s, while in SP a reduction from $T_{20;500Hz-2kHz} = 1.73$s to $T_{20;500Hz-2kHz} = 0.97$s was achieved.



(a) Dining room with absorbing ceiling panels (Gyproc) and acoustic floating floor (VH).

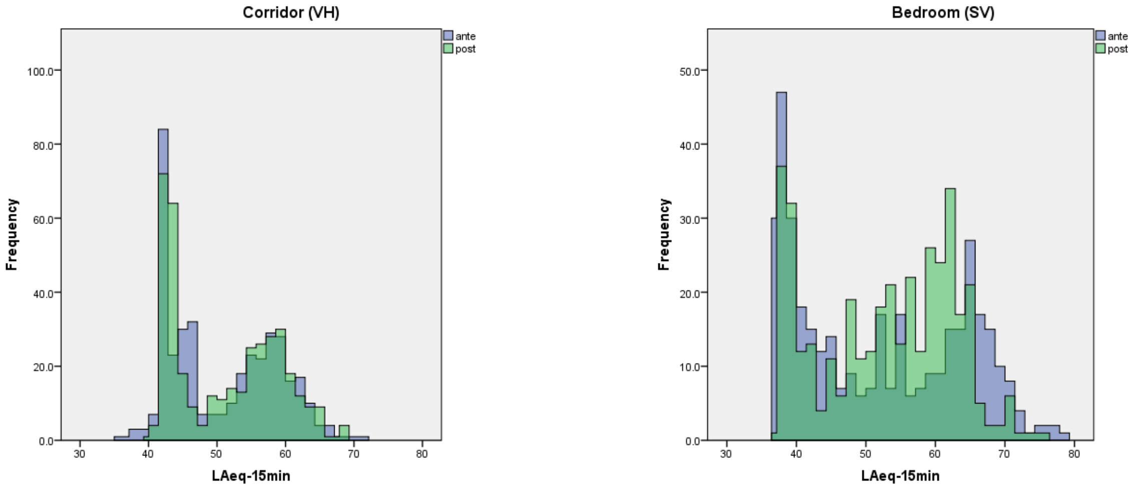
(b) Living room with absorbing ceiling panels (DOX-Acoustics) and wall panels (Gyproc) (LH).

Figure 5. Overview of the acoustic interventions in living rooms.

In order to gather further insights into possible medium-term effects of the acoustic treatments on

Table III. Summary of the acoustic improvements.

$D_{nT,w}(C;C_{tr})$	pre	post
Acoustic curtains (resident's room - SV)	29(-2;-1)dB	40(-1;-4)dB
Acoustic ventilation grill + wall panels (resident's room - LH)	20(-1;-1)dB	25(0;-1)dB
$L_{nT,w}(C_i)$		
Floating floor (living room - VH)	61(-13)dB	48(-3)dB
Floating floor (dining room - VH)	59(-11)dB	47(-4)dB
$T_{20;500Hz-2kHz}$		
Wall/ceiling panels (corridor - SJ)	1.66s	0.97s
Wall panels (corridor - SP)	1.73s	0.97s
Floating floor + ceiling panels (living room - VH)	0.91s	0.39s
Floating floor + ceiling panels (dining room - VH)	1.18s	0.91s
Wall/ceiling panels (living room - LH)	1.30s	0.57s



(a) Levels' distributions in the corridor-living room case (VH).

(b) Levels' distributions in the bedroom case (SV).

Figure 6. Noise levels' distributions for the pre and post condition.

the overall acoustic environment, similar sensor nodes as in Section 2.1 were installed to monitor noise levels after the installations. Two cases were selected as examples: the corridor-living room connection in VH (where an acoustic floating floor and absorbing ceilings have been installed in the living room area) and the bedroom in SV (where an acoustic curtain has been installed close to the door to shield the bed area from the adjacent living room). The monitoring intervals ranged from 07:00am of a Monday to 07:00am of a Friday, during a typical week of activity in the nursing homes, between November and December 2017, in order to match a similar monitoring interval as per the pre-intervention situation.

Considering the 15-minute LAeqs calculated from the sensor nodes, statistical tests were performed to analyse potential differences between the pre and post conditions, for both the corridor-living room and bedroom cases. Thus, 'acoustic treatment' was defined as a two-level categorical variable (i.e. pre and post). Two independent-samples Kolmogorov-Smirnov tests were performed to check whether the noise levels' distributions (N=768) were the same across the two categories of the acoustic treatment variable. Statistically significant differences were observed for both the corridor-living room case (D=1.479, p=0.025) and the bedroom case (D=2.165, p<0.001). Figures 6(a) and 6(b) present the noise levels' distributions in the pre and post condition, for the corridor-living room and bedroom cases, accordingly. For the former case, it can be observed that the distributions have a similar shape with a slight shift (a couple of dB(A)) towards the 'quiet', in the 40-65 dB(A) range. For the latter, the distributions look substantially different with many levels' occurrences, shifting from the extremes (quiet and loud) to the central part of the levels' range (50-

65 dB(A)). In both cases, the distributions show some 'bi-modal' patterns, with most of occurrences in the quiet or loud parts of the range. A possible explanation for this is that both types of spaces are only used during some moments of the days (and nights), thus 'silence' is often experienced.

4. Conclusions

In the first part of this paper a characterization of the current acoustical situation in five nursing homes in Flanders, Belgium was made. Firstly, typical noise levels were monitored. Highest levels were measured in living rooms, typically ranging between 55dB(A) and 60dB(A) during the day. From comparison between nursing homes, a 5dB-difference between median levels could be observed. Secondly, the building acoustic performance was measured and compared to the target values proposed by the Belgian standard. Generally, acoustic comfort in (in terms of $T_{20;500Hz-2kHz}$) and acoustic insulation between (in terms of $D_{nT,w}$ and $L'_{nT,w}$) resident's rooms complied with the standard. In contrast to this, sound insulation between corridor (and living room) and the resident's rooms was rather low, with a low average $D_{nT,w}$-value of $27.3dB$ and high average $L'_{nT,w}$-value of 66.9dB. Regarding the acoustic comfort a large spread on $T_{20;500Hz-2kHz}$ was seen for living rooms and corridors. While some cases complied to the target value of 0.8s resp. 1.2s, in most cases higher values were measured.

In the second part of this work, several interventions have been applied in order to improve the acoustic performance. The measurements conducted before and after the implementations show that with relatively limited corrections it is possible to significantly improve the acoustic performance of these facilities in terms of sound insulation (i.e. room-to-room situations), with increases of $D_{nT,w}$-values of 5dB and 11dB and decreases of $L'_{nT,w}$-values of 12dB and 13dB, and room acoustics (i.e. in-room situations), with decreases of $T_{20;500Hz-2kHz}$-values ranging between 0.27s and 0.75s seconds. Nevertheless, other issues (e.g. leaks of the doors) are more problematic to address in a retrofitting approach.

The comparison between the pre and post conditions of the data from the sensor nodes showed instead little effect on the average (one-week) noise levels measured in the nursing homes. However, increasing the amount of absorbing surfaces and materials in the investigated cases significantly reduced the reverberation times of those environments and, even if only to a small extent, it also reduced noise levels by possibly helping to contain sound propagation from specific sources. In particular, the curtain solution in one of the bedrooms of the nursing homes (SV) was quite effective in reducing the occurrences of moderately high sound levels (i.e. above 65dB) originating from outside the room (living room or corridor).

Within the broader framework of the AcustiCare project, qualitative data were also gathered through focus groups and informal talks with staff members and relatives of the residents. Overall, the acoustic interventions were positively assessed through staff members' feedback, who generally reported a more relaxed working environment and less frequent occurrences of agitated behaviours by residents (e.g. less shouting, clapping, etc.) [16].

When looking at these results it is important to bear in mind that nursing homes have very specific reoccurring functional patterns, both in terms of use of the spaces and daily routines (e.g. recurring activities and sound sources). Assessing the acoustic environments of these facilities might require a multifaceted and more articulated approach than what is commonly deployed for other residential buildings.

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