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# Acoustic model for evaluation of hospital rooms with absorbent ceilings

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A long tradition of research shows that multiple acoustic descriptors are necessary to secure good room acoustics in healthcare facilities and reverberation time (RT), Clarity (C50) and Room Gain/Strength (G) support low noise levels and good speech intelligibility. Despite this knowledge calculations according to the Sabine formula and measurements of RT according to ISO 3382-2 alone are still used to evaluate hospital rooms. In hospitals we normally have absorption material on one surface only and the decay therefore will not follow a straight line according to the theory but will be split in an early part correlating more or less to the theory and a late part with a longer reverberation time – and calculations will not always reflect reality. When testing acoustic absorbers according to ISO 354 the labs play an important role: Differences are seen from one lab to another and this together with standard deviations in repeatability and reproducibility in general, the practical absorption coefficient can be seen as a specific lab product property – not as product property in regards to acoustic design in reality. For porous absorbers it is possible to find more accurate product specific properties than the practical absorption coefficient according to ISO 354 and it is possible to calculate the acoustic descriptors RT, C50 and G in a way that is more related to activity based acoustic design in reality. The answer is Air Flow Resistance (AFR) for porous products (ISO 9053) and Miki's model can be used to calculate absorption coefficients that reflect reality and does not reflect a testing method in a lab. Ecophon has developed a tool based on Miki's model to calculate RT, C50 and G and this paper investigates and compares in situ measurements, calculations (Sabine) and results generated by the tool in patient rooms in an ICU at Borås Hospital.

## 1 Introduction

Despite the fact that many studies have shown that RT alone is not enough to describe the acoustic conditions of a room and if a room is suitable for verbal communication or – if it is a healthcare facility – supports recovery with low sound levels, it still is the main descriptor used in many countries [1, 2, 3]. RT was developed by W. Sabine in the 1890s and requires a diffuse sound field (reflexes from all surfaces/angles) and still remains the preferred descriptor even though most traditional facilities where speech and communication take place cannot be described as a diffused sound fields since most of the absorption material is often on one surface; the ceiling. Despite this, RT calculation tools based on the Sabine equation are available on-line on a lot of platforms. In hospitals in particular the ceiling is normally the only place to mount acoustic tiles.

The Sabine formula is based on the diffuse sound field theory but this is difficult to obtain in reality. Having absorption on one surface only the decay will not follow a straight line according to the theory but will be split in an early part correlating more or less to the theory and a late part with a longer reverberation time. This is thoroughly discussed and described by E. Nilsson [4, 5].

In rooms where absorption material is on more than one surface (ceiling + adjacent walls) and if the furnish is dense/heavy the sound field can be classified as diffused if. In that case the Sabine formula can be used.

In many building regulations and local guidelines for healthcare premises RT is the only descriptor to be evaluated and even when we stick to measurements we have some challenges. RT is defined in ISO 3382-2 [6] as the time it takes for sound source to decrease in level by 60 dB after the source emission has stopped. RT is more commonly measured over a 20 or 30 dB range (T20 and T30) starting 5 dB below the initial level and extrapolated to the full 60 dB range (fig. 1).

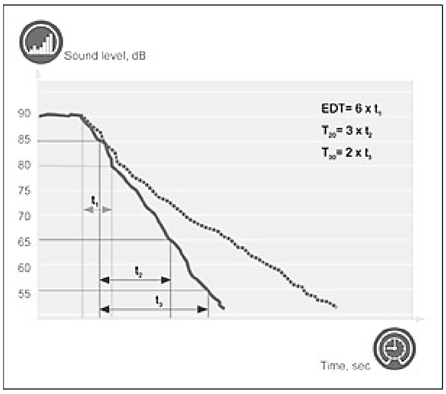


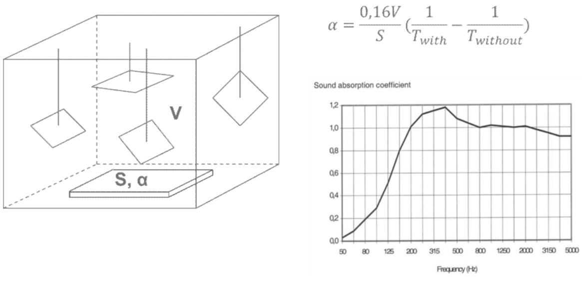
Figure 1: RT according to ISO 3382-2, EDT, T20, T30

Starting 5 dB below the initial level is problematic since this part of the decay contains a lot of information – both direct sound and early reflections – important for the perception of sound and speech clarity, which is very much important for both patients and staff. The human ear analyses so much more than the defined RT but still we need better tools to predict the actual room acoustics – not in a lab situation but in reality.

# 2. Background

## 2.1 ISO 354 and the practical absorption coefficient αp

When the Sabine formula is utilized to calculate not only RT but also as a part of predicting other descriptors, the practical absorption coefficient αp is used. To get the αp the acoustic product has to be tested in a reverberation room according to ISO 354 (fig. 2) [7].



$$\alpha = \frac{0{,}16V}{S}\left(\frac{1}{T_{with}} - \frac{1}{T_{without}}\right)$$

Figure 2: ISO 354

A product will always absorb from 0 to 1 and is evaluated in octave bands from 125 to 4000 Hz, but because of diffraction effect we can see results above 1. The reason for values above 1 is that when we do measurements according to ISO 354 we have a limited test sample area. The size of the area will influence the absorption coefficients (diffraction phenomenon) - especially at the low frequencies.

When we test acoustic absorbers according to ISO 354 the labs also play an important role: Differences can be seen from one lab to another and to be really strict the results should only be used to compare products' performance if they are measured in the same lab at the same occasion. Therefore, this together with large standard deviations in repeatability and reproducibility in general, the αp can be seen as a specific lab product property only – and not as product property in regards to acoustic design in reality.

## 2.2 ISO 11654 and the classification of products

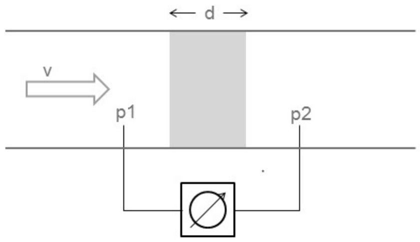
When we compare acoustic absorbers we often do it according to ISO 11654 [8] that in a simple way classifies the products from A to E (+ unclassified). This standard gives us a weighted sound absorption index and is a further simplification based on the αp that is still problematic to use. The αp values are compared to fixed reference curves and based on these the product is classified and we get the αw.

It is really easy to communicate this weighted index and αw to all target groups and it is maybe the easiest way to communicate acoustic performance to laymen, but we need to remember that this index is ‘just’ a simplified ‘version’ based on αp that – because of the method, has some challenges. Besides this a specified overall dept of system (o.d.s) must always be stated for a given absorption class since a change of the o.d.s can change the classification of the product. Besides that, this classification can also be used for constructions that contain not only acoustic absorbers (and air in the o.d.s) but also contain e.g. insulation material above the acoustic absorber. Again this index does not give us the answer to how a product itself will perform in reality but it gives us a simple comparable number based on lab results.

## 2.3 Introducing AFR – air flow resistance* / air flow resistivity**

It is possible to find more accurate real life product specific properties for porous absorbers and it is possible to calculate the acoustic descriptors RT, C50 / D50 and G in a way that is more related to activity based acoustic design in reality. It is possible to calculate absorption coefficients that are more reliable in non-diffuse settings and therefor can be used as input data in models. The answer is AFR for porous products.

AFR is a pure product specific property and the testing method does not have the same problems as mentioned describing ISO 354 and ISO 11654. Air flow resistivity** is tested according to ISO 9053 [9] and it simply evaluates sound waves’ propagation through the absorber by measuring the difference between p1 and p2 (p=pressure) and divide it by the speed (v) times the thickness of the absorber (d). (NB. Air flow resistance* is only divided by the by the speed (v)) (fig. 3).



$$Flow\ resistivity\ r = \frac{\Delta p}{v \cdot d} \quad (\frac{Pa \cdot s}{m^2})$$

Figure 3: AFR according to ISO 9053

It is important to state that there is no such thing as a ‘perfect’ AFR value for a porous absorber but for each o.d.s (overall dept of system) there is an optimum AFR. The deviations in regards to reproducibility are very low and the later calculations of absorption coefficients are not very sensitive in this range.

## 2.4 Calculations of absorption coefficients utilizing AFR

As mentioned it is possible to calculate absorption coefficients on porous products when AFR is known. Several models can be used and Delany and Bazley's model from 1970 is empirical (1):

$$Z_c = \rho_0 c_0 \left[ 1 + 0.0495 \left( \frac{f}{\sigma} \right)^{-0.754} - j0.0754 \left( \frac{f}{\sigma} \right)^{-0.732} \right]$$

$$\gamma = \frac{\omega}{c_0} \left[ 0.164 \left( \frac{f}{\sigma} \right)^{-0.595} + j \left\{ 1 + 0.0848 \left( \frac{f}{\sigma} \right)^{-0.700} \right\} \right] \tag{1}$$

- and it forms the basis for other models today. Erling Nilsson has chosen to use Miki's model from 1990 that is developed from Delany and Bazley's model – but is a bit more accurate on the lower frequencies [10, 11, 12, 13]. Using these models, we get an absorption coefficient that reflects reality in non-diffuse settings and does NOT just reflect a testing method in a lab. It is worth mentioning that large differences in AFR (by number) don't always give big differences in the end. (fig. 4)

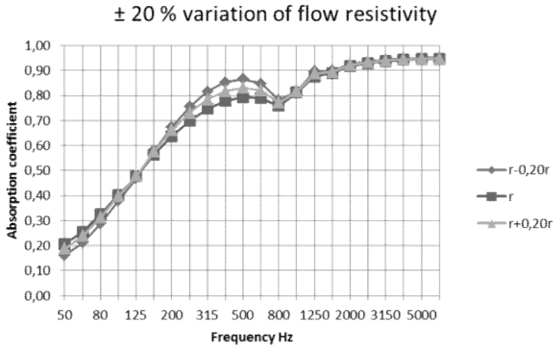


Figure 4: Calculation of absorption coefficients using AFR

In short – when we know the AFR of a porous absorber we will have the possibility to calculate more accurate absorption coefficients (α) – and then we can calculate not only RT but also other acoustic descriptors like C50 and G.

Calculations based on AFR will often show 'worse' results (for RT, C50 and G) than what we can calculate using the Sabine equation and αp – but the results will be more accurate when we compare it to what actually happens in reality – shown in many measurements. We must never forget that the Sabine equation in itself is based on a condition that is difficult to obtain in reality. On top of this αp according to ISO 354 is to be seen as a PRODUCT parameter which is influenced by the measurement procedure – and not directly an applicable design parameter.

AFR should never be an argument in itself in regards to what products perform 'best'. AFR is a product property that helps us to calculate more accurate acoustic descriptors relevant for educational, office and healthcare facilities.

# 3. The room acoustic calculator

## 3.1 Introduction

The calculator tested in this paper is a tool to calculate room acoustics – utilizing AFR as a true product specific property and NOT a property heavily related to the test method ISO 354. The calculator will show calculations on T20, C50 and G based on the model but always also show the Sabine calculations on RT – since this is commonly used by acousticians (and a way to secure transparency). It is important to stress that the Sabine calculation will be used in cases where the room is analysed to be diffuse. The sound scattering effects of furniture and other equipment in the rooms have a large influence on the room acoustic parameters. Especially reverberation time T20 and Speech Clarity C50 are affected. Sound Strength G will normally be less affected [14]. The model behind the room acoustic calculation tool – including the effect of scattering is developed by Erling Nilsson and is described in detail in his proceeding for ICSV24 [10].

## 3.2 Intervention study from Borås

The data used to test the calculator is taken from a research study at Borås hospital, where both the original ceiling treatment and furnish were changed in a patient room [15, 16]. Measurements were done in different steps as seen in table 1:

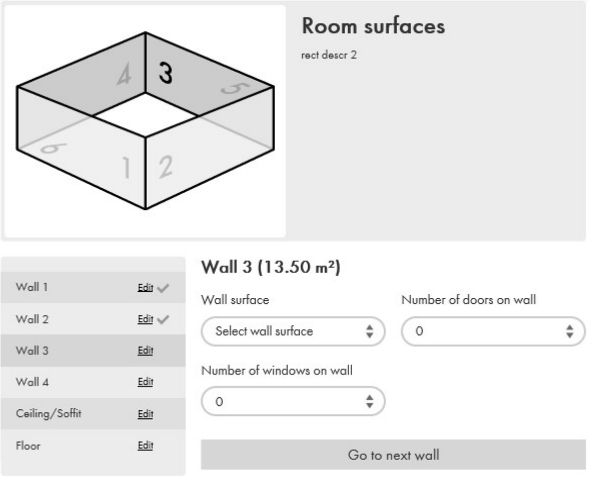
Table 1: Measurements at Borås Hospital

| Measurement | Room conditions – ceiling treatment |
|---|---|
| #1 | Original ceiling – suspended gypsum – no furniture |
| #2 | No ceiling treatment – no furniture |
| #3 | With acoustic ceiling – no furniture (Ecophon Labotec) |
| #4 | With acoustic ceiling– with furniture (Ecophon Labotec) |
| #5 | With acoustic ceiling + low frequency absorber (Ecophon Labotec + Xbass) – with furniture |

The room had the following characteristics: Ceiling height: 2.7 m. Volume: 77 m3. Floor area: 28,5 m2. Walls: Hard surfaces, concrete + gypsum. Wall 1: 2 windows, 1 door. Wall 2: 1 small window, 1 door. Wall 3: 1 door (to toilet). Wall 4: No windows/ doors.

Measurement no. 4 has been used to compare with the 'new' room acoustic calculations and Sabine calculations.

NB. The comparisons have been made in a beta version of the calculator. The first version will be launched the 1st of March 2018. On BNAM2018 more of the measurements will be presented for comparing with the room acoustic calculations. In the calculation tool the following has to be put into the system: Segment (healthcare, education, office), room type (ex. Patient room, meeting room), room dimensions, room surfaces (doors, windows, ceiling, floor) (fig. 5), suspended ceiling, wall absorbers, furnishing (sparse, medium, dense).



Room surfaces

rect descr 2

Wall 3 (13.50 m²)

Wall surface: Select wall surface

Number of doors on wall: 0

Number of windows on wall: 0

Figure 5: Room acoustic calculator – example of input data

Normally sound scattering due to furniture is not included in online calculations tool but this energy based model it is possible to choose between three different scenarios (sparse, medium, dense).

## 4. Results and concluding remarks

When the actual measurements are compared with both Sabine calculations and the new room acoustic calculator we see the following results (fig. 6).

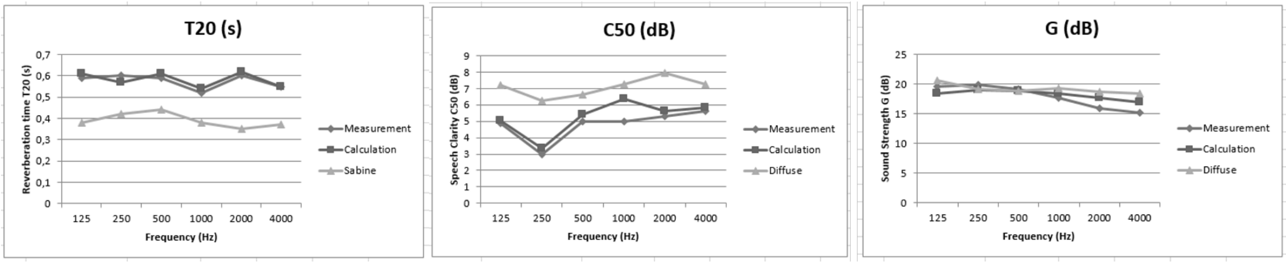


Figure 6: Comparison in situ measurements, Sabine calculations (called ‘diffuse’), ‘new’ room acoustic calculations (called ‘calculation’).

The results show a good correlation between the in situ measurements and the calculations made by the new calculation tool in all parameters. The Sabine calculations, one the other hand, show remarkably better results on both T20 and C50 than both the measurements and ‘new’ room acoustic calculations – and this is expected since the patient room is not diffuse. There are no wall absorbers in the room – all the absorption is on one surface only (the ceiling). It was sparsely furnished (scattering is low) and the grazing sound field in the real room also is not considered in the Sabine calculation. The room acoustic descriptor Room Gain shows good correlations on both calculations and measurement, which is also expected since Gain will normally mostly depend on the room’s total absorption.

Today Sabine calculations are utilized to predict room acoustics in hospital buildings and it is worth noticing that these calculations could show ‘just’ an indication of the room acoustic quality but does not reflect reality - if the room is not categorized as a diffuse sound field. It is also worth mentioning that the Sabine calculations normally give better values than what happens in the real room. Wall absorbers are not familiar in healthcare facilities in all rooms (because of hygiene reasons) but when the absorption is no longer on one surface only the conditions get closer to diffuse conditions. However – in most cases today the absorption is still on one surface only.

# References

[1] J. S. Bradley et al, A just noticeable difference in C50 for speech, Applied Acoustics. 58, 99ff, 1998

[2] W. Yang, J. S. Bradley, Effects of room acoustics on the intelligibility of speech in classrooms for young children. J. Acoust. Soc. Am. 125 (2). 2009

[3] J. S. Bradley et al, On the combined effects of signal-to-noise ratio and room acoustics on speech intelligibility, J. Acoust. Soc. Am. 106 (4), 1820ff. 1999

[4] E. Nilsson, Decay Processes in Rooms with Non-Diffuse Sound Fields Part I: Ceiling Treatment with Absorbing Material, Building Acoustics, 11, 39ff. 2004

[5] E. Nilsson, Decay Processes in Rooms with Non-Diffuse Sound Fields Part II: Effect of irregularities, Building Acoustics, 11, 133ff. 2004

[6] ISO 3382-2: Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms.

[7] ISO 354:2003: Acoustics -- Measurement of sound absorption in a reverberation room.

[8] ISO 11654:1997: Acoustics -- Sound absorbers for use in buildings -- Rating of sound absorption.

[9] ISO 9053:1991: Acoustics -- Materials for acoustical applications -- Determination of airflow resistance.

[10] E. Nilsson, Input data for acoustical design calculations for ordinary public rooms, ICSV24, London, 2017

[11] M. E. Delany and E. N. Bazley, ‘‘Acoustical properties of fibrous absorbent materials, Applied Acoustics 3, 105–116, 1970.

[12] Y. Miki, Acoustical properties of porous materials — Modifications of Delany-Bazley models, J. Acoust. soc. Jpn. (E), 11, 19–24, 1990.

[13] T. Komatsu, Improvement of the Delany-Bazley and Miki models for fibrous sound-absorbing materials, Acoust. Sci. & Tech. 29, 2 (2008)

[14] Nilsson, E. " Sound scattering in rooms with ceiling treatment " NT Techn report 606, Nordic Innovation Centre, 2007.

[15] L. Johansson et al, The sound environment in an ICU patient room——A content analysis of sound levels and patient experiences, Intensive and Critical Care Nursing, Volume 28, Issue 5, Pages 269–279 (2012)

[16] L. Johansson et al, Meanings of Being Critically Ill in a Sound-Intensive ICU Patient Room - A Phenomenological Hermeneutical Study the Open Nursing Journal, 2012, 6, 108-116