

Understanding and detecting non-diffuse rooms

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v2, long corridor shape

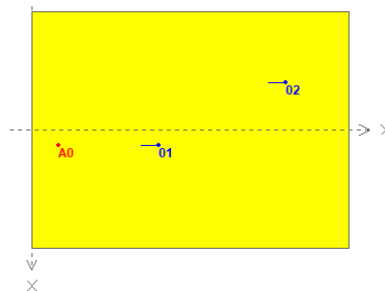
1. Introduction

The background to this document is that since the last say 10-15 years “design”, and thereby prediction of, non-diffuse rooms likely dominates the use of GA-based software prediction (sports halls, classrooms, foyers, open plan offices etc.) but it seems that especially new individual users do not realize when a room is non-diffuse and why, probably it never came up in the user’s education in acoustics (if any). In several cases it has even been assumed that if T-30 does not match Sabine it is a software error that has to be “fixed” by setting very high and unrealistic scattering.

From *TUCT* v2.0h three new Show2D displays based on B-format IRs are added: *[Measure] T-30 WXYZ* and *T-20 WXYZ* and *[Echogram] Schröder WXYZ* that essentially are of educational nature to clearly illustrate what will be discussed below, they don’t only show if a room is non-diffuse but also *why* even if the room shape and absorption distribution really should be sufficient to realize it. For most of the examples below these new displays will be shown along with the normal T-30 band-values. It is possible to see *T-30* and *T-20 WXYZ* and *Schröder WXYZ* displays also when loading old *TUCT2* predictions.

Notes:

- non-diffuse rooms are generally of fairly rectangular shape and then it is best for this analysis to set the receiver head-direction for all receivers along the negative y-axis and that will make the B-format X IR be along this axis and B-format Y along the x-axis, and Z will be up. Overall this will also, e.g. when auralizing, make it easier to recognize a position than if the direct sound always comes from the front (as it will with the Head direction “Source” position in CATT-A General settings). If the receivers are not aimed that way it will be harder to analyze the reason for the non-diffuseness. Since this type of analysis should be made early in a project another head direction can if needed be used after the room has been improved.



- these displays will only be shown when a single source result is requested (such as A1*01) and not for source sum (such as *.01).
- if e.g. Y T-30 is much longer than W T-30, as it often is for typical non-diffuse rooms with a ceiling absorber, the select IR length may be too short to evaluate T-30 and the values for Y T-30, for one or more bands, are shown at zero. A longer IR length then has to be used and a recalculation made.

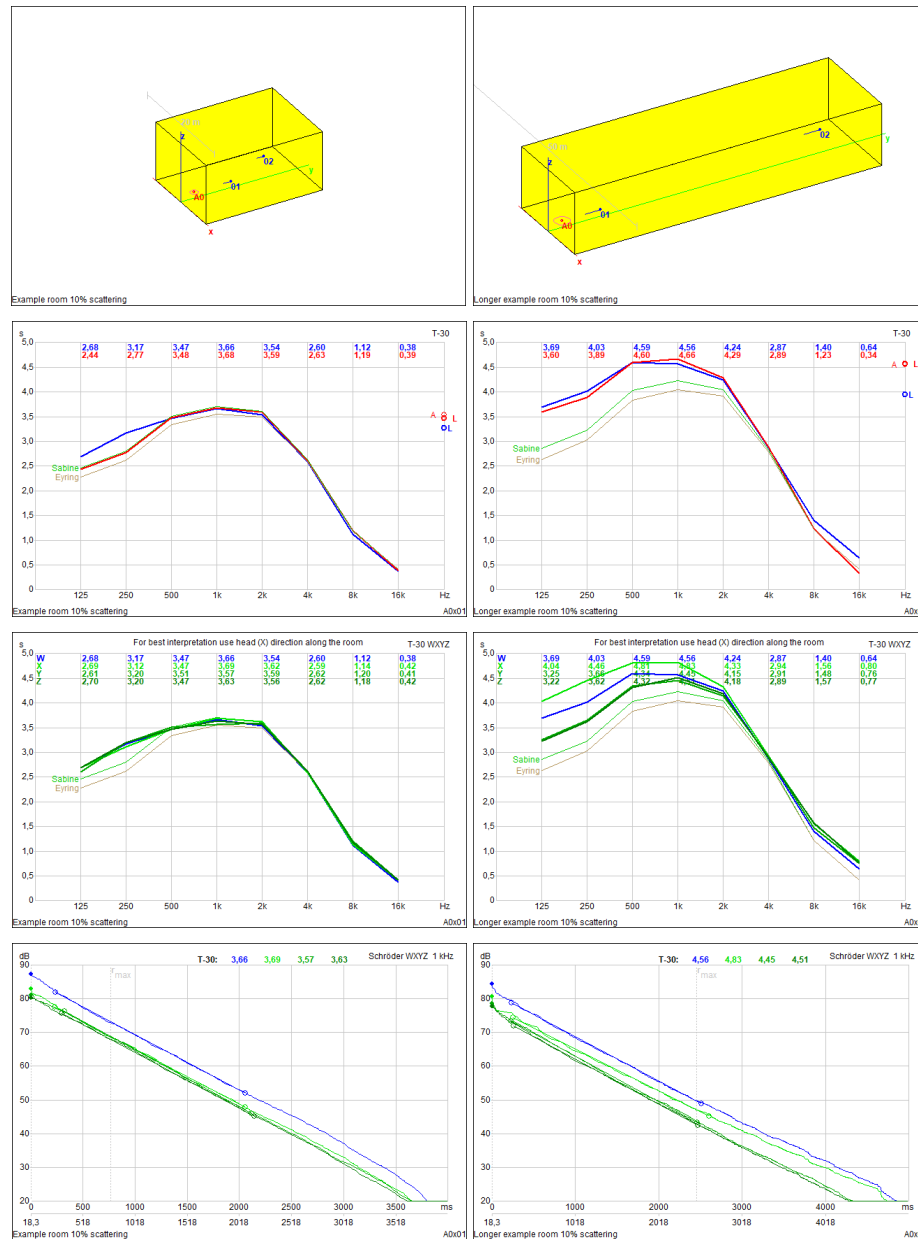
1. Why can rooms be non-diffuse?

Rooms can be non-diffuse for several reasons:

1. Their shape (typically rectangular) when the x, y and z dimensions differ

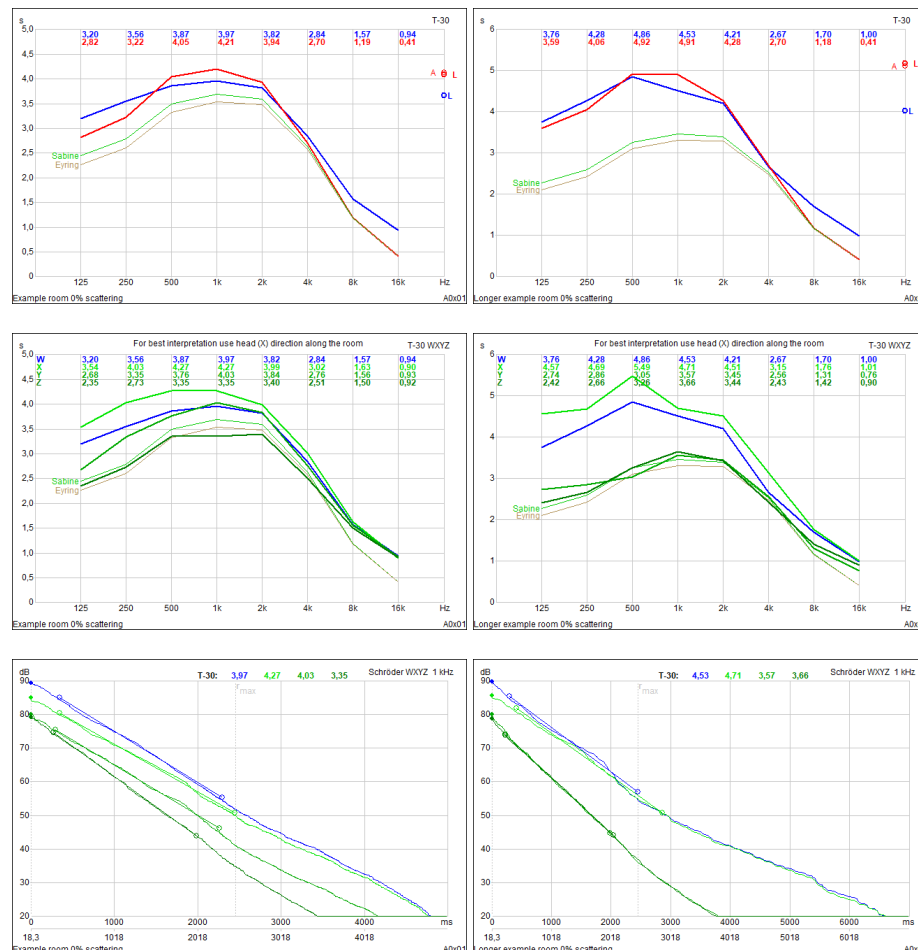
As an example, a rectangular room with *uniform* absorption (9% at 1k) and scattering (10% at 1k) appears diffuse with length x width x height = 20 x 15 x 10 m³ (at 1k Sabine = 3.68 sec, *TUCT* predicts

3.68 sec, left figure). However, it will no longer be diffuse if the ratio is changed to e.g. $50 \times 15 \times 10 \text{ m}^3$ (at 1k Sabine = 4.21 sec, TUCT predicts 4.66 sec, right figures). Note that the 10% scattering is high for big plain surfaces but the effect of scattering itself, and especially with very uneven but very common absorption distributions, will be exemplified below where the difference to Sabine will be dramatic.



In the proportional room case the reflections in all dimensions die out at a fairly equal rate while in the long room case the vertical reflections will die out first, the horizontal reflections in the short dimension will die out second, and the horizontal reflections in the long dimension will die out last and essentially determine T-30. The T-30 WXYZ and Schröder WXYZ displays show this and also which dimension dominates the T-30 values.

As a further example the two rooms above will be shown with all surfaces having 0% scattering showing that the non-diffuseness then increases (note that *the absorption is still uniform*, in section 3 below also have common absorption distributions that strongly increases the non-diffuseness).



One can say that if Sabine had not happened to perform his experiments in a diffuse enough room he would not have found his formula. Later attempts like Fitzroy (1959) and Arau-Puchades (1988) where the x y z average absorptions are used has had limited success and are not easy to apply for non-rectangular rooms (the non-diffuseness does not require a room to be exactly rectangular). However, Sabine remains an extremely important *reference* but a further complication is that the majority of course-books in room acoustics, especially of the type “Handbook in Acoustics” seem to show the Sabine equation without the necessary air absorption included.

2. The absorption placement

Typically only on the ceiling, on one surface, or on two opposite surfaces. Here the biggest and most common issue is using only a ceiling absorber and worse if the room width and depth are much bigger than the height, as e.g. in many big open plan offices. In such cases it is logical that adding more absorption only to the ceiling actually will make T-30 *longer* since then the non-diffuseness is increased but has also in several cases been assumed to be a software error.

3. A lack of scattering objects and/or scattering surfaces

As a test set an artificial 100% scattering for all surfaces and bands and just about any room will become diffuse. *TUCT* has an option for that in *File | Save Modified CAG As* and it is also a useful model check, if that does not result in Sabine (or Eyring if the mean absorption is high) the model either has issues, such as overlapping planes (that then will be taken into account for Sabine but rays will not hit both planes), or it is an unusual shape, or it consists of coupled volumes.

4. Combinations of 1, 2 and 3

5. Coupled volumes

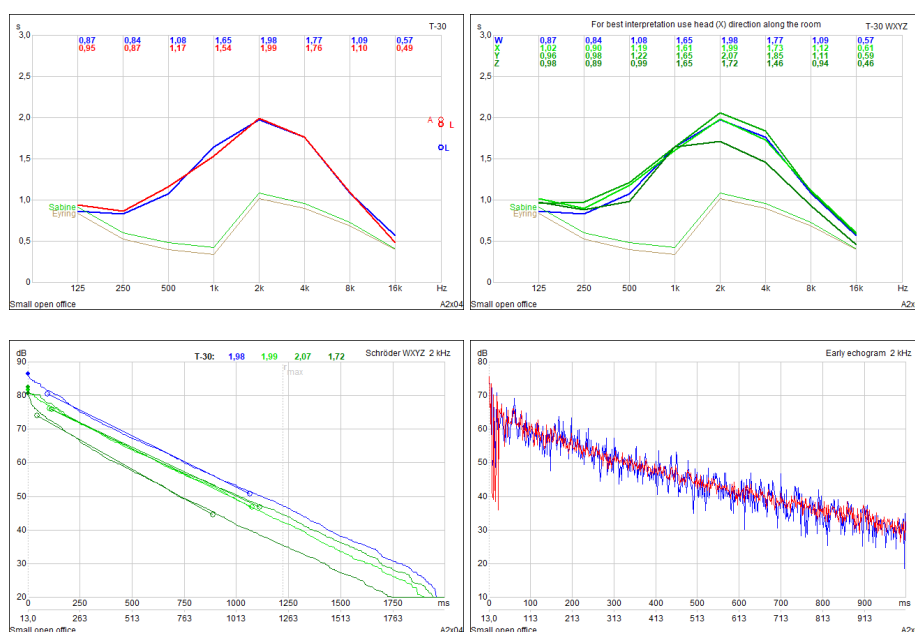
Rooms with coupled volumes will be non-diffuse in the sense that T-30 can differ from Sabine, but setting an artificial 100% scattering will then not make them become diffuse. Typically the decay then has a double slope i.e. the early and late reverberation times differ to a high degree.

3. Examples of existing non-diffuse rooms

The cases below are based on a number of room models received from users typically with questions about why T-30 does not become = Sabine. Probably there is a high “dark number” of users that have “fixed” the “wrong” prediction by artificially increasing the scattering to achieve T-30 = Sabine. In addition there is at least one much used software that actually will predict close to Sabine even if the actual T-30 is much longer. One wonders if there no longer are any measurement verifications made that then would have shown that the actual T-30 turned out to be much longer than the predicted Sabine. These rooms have to be anonymous and only the principle layouts will be indicated. Some may see this “pointing a finger” unfair, even if the room model is not shown and neither country nor consultant is named, but for the sake of room acoustics I see no other way. The last decade extremely few questions have been asked when at the same time more and more user individuals have little to no background in acoustics. At the same time fewer and fewer teachers in room acoustics also have no background in acoustics, in several cases the students are even just set to use the too limited demo version and it has even in some cases been used for M.Sc. thesis.

3.1 A small open office with absorbing ceiling and floor (carpet), furniture not yet added

A square shape 12 x 12 x 2.55 m³ but with a 6 x 6 m³ entrance area sticking out.

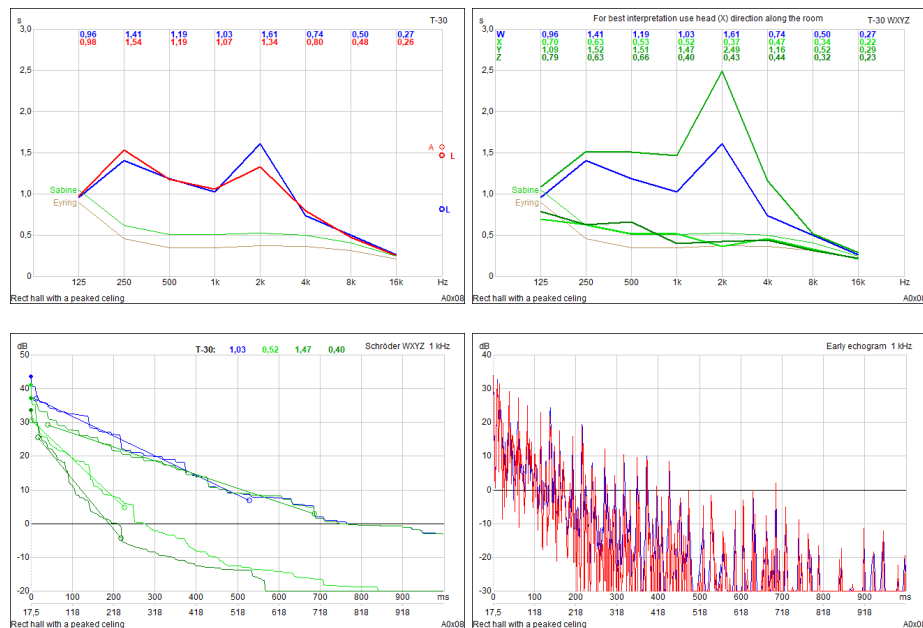


Note from the Schröder WXYZ (here shown at 2 kHz where the difference is bigger) that the lower curve (for Z) will not contribute much to T-30 that instead is determined by the reflecting walls. This room will not have a very pronounced flutter at the position due to the horizontal square room shape. Adding furniture will improve the case but the small size of chairs, seats etc. makes it difficult to assign proper scattering. Normally in GA (too) small objects are omitted but here there will be so many and will affect the acoustics that they have to be included and have auto-edge scattering assigned. Open offices will also have massive diffraction (screens, tables and chair edges) that even if low order real diffraction is available in *TUCT* there are many diffraction paths so it would take a very long time to predict. In addition many edges are not hard and the BTM theory used does then not hold. Overall open offices are

actually harder to predict well with GA than the finest concert halls since those are essentially diffuse and have larger surfaces. The difficulty with concert halls rather lies in deciding how to design them.

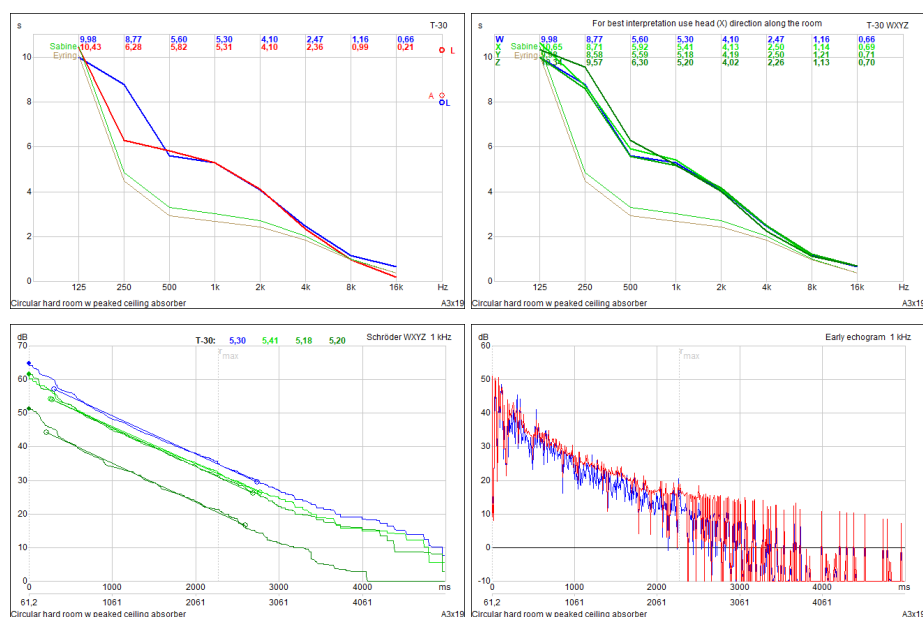
3.2 A rectangular room with a peaked absorbing ceiling

A rectangular room, $16 \times 13 \times 9 \text{ m}^3$, (side walls 4 m high) with high absorption placed on the peaked ceiling and on the two parallel end walls leaving the two parallel side walls reflecting. The floor is hard and the only other absorption will come from standing and mingling persons. This room naturally will also have a big flutter between the two reflecting side walls. An almost identical design was received from another consultant user that asked why T-30 became longer when the ceiling absorption was increased. It seems very clear that there is, or has developed over time, a “hole” in the understanding of how non-diffuse rooms function but the second consultant had actually been working for 20 years.



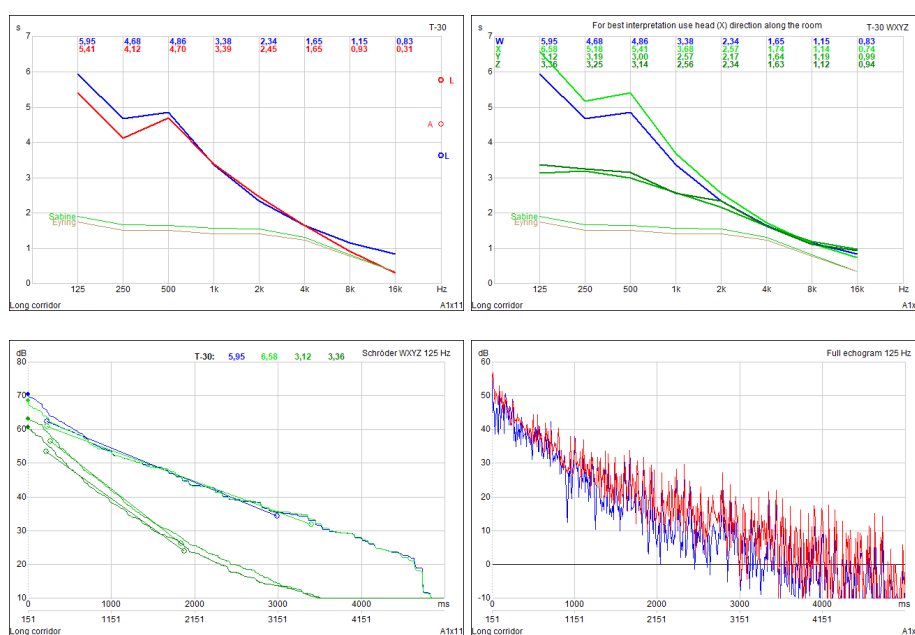
3.3 A high circular building with a peaked roof

A “hut”-like almost circular room, 40 m diameter x 26 m^3 high (walls 18 m high), the only absorption on the ceiling. This type of room naturally has big wobbling flutter echoes. The separation of the X and Y decays are not seen here due to the circular shape but the vertical Z decay is 10 dB lower.



3.4 A long corridor shape with absorbing ceiling

A nearly rectangular 96 m long corridor (some niches with entry doors along the walls), $96 \times 17 \times 5.5 \text{ m}^3$, with high ceiling absorption and a thin wall carpet, plaster walls. The use was for coffee breaks but no furniture was included in the prediction that that will increase the diffuseness. As received the model had very high and even scattering on all walls, possibly due to omitted small objects but also likely to try to “fix” the prediction to become closer to Sabine. This room naturally also had a short flutter between the two reflecting side walls and a long but weaker for the long dimension. The person actually making the model, and that had set data, had no background in acoustics, perhaps the reasoning of the superiors was “it is just a coffee break area how hard can it be?”. However, a supervisor had also been involved and did not see anything wrong. The question that led to sending the model was why no T-30 values were given at low frequencies, it was probably assumed that T-30 would be = Sabine. A high number of trials had been made to find the reason (Can it be due to this? No. Can it be due to this? No. Repeat). The graphs below were made with 10 M rays due the very uneven absorption and elongated shape. This is one example of many where how T-30 is predicted or measured, i.e. having a sufficiently long IR covering at least down to -45 dB for T-30, had not been understood, or here learned. In numerous cases, even in university courses in room acoustics, it has even been taught that T-30 is the decay time for 30 dB (i.e. that “T-60” = 2·T-30 and the 28 viewgraphs for that course did not mention *diffuse*, *flutter* or *scattering* but on the other hand not even *Sabine* was mentioned in this 28 page long *Room Acoustics (1)* course.



4. Further consequences of non-diffuse rooms

Among the many undesirable effects of a non-diffuse room is that the risk for flutter echoes increases. Flutter echoes are not always apparent in the Schröder decay curves since the backward integration smoothes them out, or if visible it is in the form of a staircase shape. However, flutters are much more clearly seen in the echograms and IRs and are heard when listening to the bare IRs. It can be heard also with the basic version.

Yet another problem is that non-diffuse rooms are harder to predict with GA since the case becomes more sensitive to both absorption and scattering coefficients, and maybe even requires actual angle - dependent absorption. Absorption is always uncertain to a degree due to the measurement method (that assumed a diffuse field), especially at high α , and of course also scattering that has to be estimated based on wavelengths related to surface size and/or surface irregularities. There are often also quite few materials in non-diffuse rooms so then naturally the accuracy of the absorption has a higher impact while

with many materials the errors may average out. Additionally many more rays are required for non-diffuse rooms. However, how well does a non-diffuse room really need to be predicted? In most cases it is sufficient to see that it is non-diffuse and the main task must then be to make it more diffuse typically to have a lower T-30 and a better and more even acoustics without flutter echoes.

T-30, that traditionally (and typically as taught), is assumed constant over a room except close to the source but with non-diffuse rooms it may not be so. Additionally, the overuse of averaging results, even in standards (some measures should never be averaged but still are) can hide that the room in question will have very varying measure-values such as D-50 across the room, i.e. there may be many “bad spots” of various types or where odd phenomena are heard, such as flutter echoes or a colored sound.

In general non-diffuse rooms are actually often not well predicted, or even not at all, with all types of GA algorithms in use where some algorithms literally are based on (assume) that the room is diffuse. T-30 may then be predicted as if the room were diffuse, i.e. close to Sabine when the actual T-30 can be 3 times longer or more. The background is that when those algorithms were initially developed early 1990ies, most rooms modeled actually were diffuse (concert halls and auditoria). Additionally with such algorithms flutter echoes can be totally missed or become very weak. Sometimes special exaggerated settings or special code can be used to “illustrate” e.g. a flutter but it is anyway missed in the main prediction algorithm for T-30, D-50, EDT etc. and auralization. That such algorithms continue to be widely used, apparently without questioning them or software users realizing it, does not put current room acoustic consulting and research in a good light. It also suggests that way too few predictions are compared to measurements, or too seldom since comparing with just a few predictions may randomly happen to be good or bad and will say little, comparisons need to be made for every project.

The impact of the user is also very high since no matter how good a prediction algorithm may be if the input data is not well set, too few rays, or a too short echogram/IR length is used, the prediction will naturally not be good. Since some years *TUCT* has warnings or don't give any T-30 values if the IR is too short, it did not use to be necessary. As a telling and amazing example in a recent “reviewed” article, where two software were used, the IR length for the *same room* was set different in the two software. In software A it was set to 3000 ms while for software B to 731 ms. The rationale (if any) behind those numbers was that 3000 ms for software A was chosen referring to an article with *another room* while 731 ms for software B was chosen based on an initial length suggestion assuming a diffuse room (the room in question was not). A proper length would have been 900 ms for *both* software it being a parameter that is related to the *room* and not the software used. There is a more thorough discussion about the user's side in

http://www.catt.se/GA-Prediction_vs_Measurements_how_close_can_they_be.pdf

Non-diffuse rooms may also be perceived as not sounding natural when e.g. there is very little vertical reverberation that will not mask disturbing horizontal sounds.

A non-diffuse room measured or predicted using an omni-directional source will likely have a different T-30 if a directive source (such as a human talker) is used and also depend on the source aim. If the only absorption is on the ceiling, as in many rooms such as open plan offices now, a horizontally aimed directive source will show a longer T-30 than a vertically aimed one. Similarly if the microphone used is directive the aiming will affect the measurement.

A non-diffuse room will typically have a T-30 that varies across the room, which may or may not be a problem, but it can also have spots where a flutter or other non-benign phenomena are disturbing.

Sidebar with some history: Quite many, it may even be a majority, of GA-software users find B-format very mysterious when it actually was developed already around 1970, 54 years ago, and has been created by *CATT* software since 1990 and *TUCT* predictions are almost totally based on B-format (all the nine IR display options in “*Impulse response*” are to various degrees based on B-format, and **Utilities | Save SxR** have more and it is also used in *Walker*). Here I mean 1st order B-format W omni, X(front), Y(left) and Z(up) figure-of-8 directivities (positive pickup in the front lobe, negative in the rear lobe) that even if it has its limitations, and some turn to higher orders (*TUCT* can create do up to 3rd

order IRs but 2nd and 3rd only for export). 1st order is quite intuitive while with higher orders one has to “rely on the math” so it is more of a black box. Also, if an initial prediction is not good due to the algorithm used, and/or the IRs are created using various tricks often starting off with an energy echogram summing in say 3 ms time buckets and limited angular resolution, converting that to a 3rd order B-format IRs (16 channels), or even 1st order, is like putting lipstick on a pig.

5. Roundup

The new T-30 WXYZ option in TUCT v2.0h (on the Show 2D Measures menu) will directly show the XYZ T-30s with the W (h) T-30 as a reference and via the SxR control all SxR combinations can quickly be scrolled through, similarly the Schröder WXYZ (on the Echogram menu) will show the decay curve in each genral direction. Be prepared for some surprises and also some Huh? that hopefully will lead to some thinking and then be replaced by a resounding Aha!!! The goal for me when developing the software has always been that it should be useful for a better understanding of the acoustics of a room, else how can the acoustics be improved? Trial and error? That type of “investigating” use is vanishing fast, it seems only interesting to get T-30 numbers, or even T-20 (and not much more) and not what created them, i.e. understanding the room does not seem to come into it, and it means that very little is learned from each room. Some may wonder why this T-30 WXYZ has not come until now but a part of the overall problem is that very few have asked questions, and sent models, the last 10-15 years so I have simply not seen that it has become so very common to “design” rooms that are non-diffuse but when I recently saw what example 3.1 is about I realized that these types of rooms and absorption placements are now probably very (even amazingly) common. Initially, when I saw this room, I simply listened to, looked at and compare the W, X, Y, and Z IRs and that has been possible since many years.

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