LUND UNIVERSITY
ENGINEERING ACOUSTICS, LTH

# Reverberation time exercises – *Ljud i byggnad och samhälle* (VTAF01)

**<u>Example 1</u>** (found in older exams 2016)

In an empty reverberant room with the dimensions 5.6 × 5.6 × 4.8 m3, the following reverberation times have been measured for different frequencies:

| *f* (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|
| $T_{60}$ (s) | 8.0 | 7.8 | 7.3 | 6.7 | 6.4 | 5.8 |

a) Calculate the average absorption coefficient of the walls / floor / ceiling for each frequency. (5p)

b) A 1 $m^2$ lamp specially designed as sound absorber now hungs in the room and the reverberation time is measured again with the following results:

| *f* (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|
| $T'_{60}$ (s) | 7.5 | 7.2 | 6.4 | 6.2 | 5.7 | 5.5 |

Determine the absorption area of the lamp for the different frequencies. (5p)

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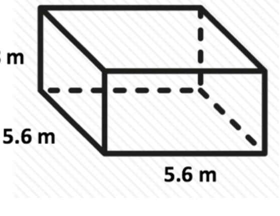
**Example 1 - Solution**

**a)** V = 5.6 × 5.6 × 4.8 = 150.5 $m^3$ …is the volume (V) of the room.

<u>Sabine's reverberation time</u> is defined as $\boldsymbol{RT} = \boldsymbol{T_{60}} = 0.16\,\frac{V}{A} = 0.16\,\frac{V}{\sum aS}$




***… which is the time for an impulse response signal to decay 60 dB in a closed space. A is the absorption area and α is the absorption coefficient, both quantities are frequency dependent;*** *they have a certain value for each octave band in the freuqency range of interest (125 Hz to 4kHz in this case). S is the surface of every wall with its own absorption coefficient inside the closed space.*

Hence, $RT = 0.16\,\frac{V}{\sum aS} = \frac{0.16\,V}{a(2*5,6*5,6)+a(4*4,8*5,6)} = \frac{0.16\,V}{a*S_{tot}} \leftrightarrow a = \frac{0.16\,V}{RT*S_{room}} = \frac{0.16*150.5}{RT*170.24}$

***Note –*** *There is 2 surfaces of 5.6*5.6 $m^2$ (floor, ceiling) and 4 wall surfaces of size 4.8*5.6 $m^2$. The total surface $S_{room}$ is the sum of them.*

Finally, using the given values for RT ($T_{60}$) we complete the table as:

| $f$ (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|
| $T_{60}$ (s) | 8.0 | 7.8 | 7.3 | 6.7 | 6.4 | 5.8 |
| ***a** (Hz)* | *0.0177* | *0.0181* | *0.0194* | *0.0211* | *0.0221* | *0.0244* |

**b)** There is a new reverberation time now including the lamp as an object with absorptive surfaces.

***Note -*** *The volume stays constant (same closed space) but the overal surface areas are changed now!*

The new RT' (or new $T'_{60}$) is calculated as:

$$RT' = 0.16 \frac{V}{\sum aS'} = \frac{0.16\, V}{aS_{room} + a_{lamp}S_{lamp}} = \frac{0.16\, V}{A_{room} + A_{lamp}}$$

$$\leftrightarrow \; A_{room} + A_{lamp} = \frac{0.16\, V}{RT'}$$

$$\leftrightarrow \; A_{lamp} = \frac{0.16\, V}{RT'} - aS_{room}$$

Then, we can calculate the next table for $A_{lamp}$ as following:

| $f$ (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|
| $T'_{60}$ (s) | 7.5 | 7.2 | 6.4 | 6.2 | 5.7 | 5.5 |
| $A_{lamp}$ | 0.2007 | 0.2573 | 0.4640 | 0.2899 | 0.4621 | 0.2265 |

**Example 2** (found in older exams 2017 – Uppgift 5)

a) An empty room with dimensions 4 * 5 * 3 $m^3$ has a reverberation time of 3 seconds (we assume that it is constant for all frequencies). How many people, with an absorption of 0.40 each, do you need to take into the room so that the reverberation time is 1 second?

b) In the same room, the floor and ceiling have an average sound absorption coefficient of $\alpha$ = 0.04, and all wall surfaces have $\alpha$ = 0.15. Sometimes two windows open in the room with an area of 4 $m^2$ each. Calculate the reverberation time with the windows closed and open, and justify your assumption for the absorption coefficient of the windows. Are the values good for a good acoustic design?

c) Is the reverberation time a good measure of how people experience the acoustics of a room? Is Sabine's formula correct? Why (or why not)? What other parameters could you use instead (for room acoustics)? Do they fit better with how humans experience sound?

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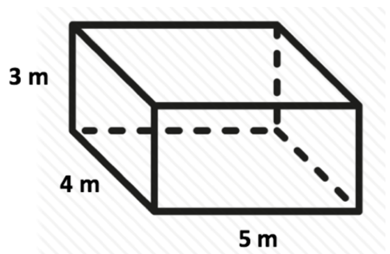
**Example 2 - Solution**

**a)** V = 5 × 4 × 3 = 60 $m^3$ …is the volume (V) of the room.




***Another room which is empty at first and then absorption elements are added inside, that is a usual topic in room acoustics. Such elements can be: furniture, rugs, absorption panels for studios or offices...*** *But it can be also real persons, since they have such propeties – human absorbers matter a lot in acoustic modeling of music halls and auditoria!*

Using Sabine's formula we have:

$$RT_{empty} = 0.16 \frac{V}{A_{empty}} = 3\,s \quad \text{and} \quad RT_{full} = 0.16 \frac{V}{A_{full}} = 1\,s$$

Then we calculate $A_{empty}$ = 3.2 $m^2$ and we alsoderive the relation: $A_{full} = 3 * A_{empty}$

**Note - We have to assume that the volume V is constant in this case,** which is not the total truth, The human bodies have some volume, so they affect the total volume of free air in a test room. But this is an aprroximation which happens usually for simplicity.

We estimate also that:

$$A_{full} = A_{empty} + A_{humans} \leftrightarrow 3 * A_{empty} = A_{empty} + A_{humans} \leftrightarrow 2 * A_{empty} = A_{humans}$$

Thus $A_{humans}$ = 2*3.2 = 6.4 $m^2$ = $a_{humans} * S_{humans}$ , If $a_{humans}$ = 1, assuming full absorption, then $S_{humans} = \frac{6.4}{0.4}$ = 16 m$^2$ ,

which corresponds to N = 16 persons roughly.

Of course there are the assumptions here that: room volume stays the same, $a_{humans}$ = 1 and the the surface area of 1 person is 1 m$^2$. There should be better definitions in those instructions. But all that assumptions are reasonable and can be done if not stated otherwise in the exercise.

**b)** Again V = 60 m$^3$ and now we compare two different cases of reverberation time. There is also two different absorption coefficients for horizontal surfaces (floor, ceiling) and walls, given as:

$a_{floor}$ = 0.04 and $a_{walls}$ = 0.15

$$RT_{closed} = 0.16\,\frac{V}{\sum aS} = \frac{0.16\,V}{2*4*5*a_{floor} + 2*3*5*a_{walls} + 2*3*4*a_{walls}} = 0.99\text{s}$$

***Note** – there are different surfaces with different sizes grouped as above: floor/ceiling (5*4m$^2$), long side walls (5*3m$^2$) and short side walls (4*3m$^2$).*

$$RT_{open} = 0.16\,\frac{V}{\sum aS} = \frac{0.16\,V}{2*4*5*a_{floor} + 2*(3*5 + 3*4-4)*a_{walls} + 2*4*a_{windows}} = 0.58\text{s} \quad \text{for } a_{windows} = 1$$

***Note** – the window total surface (2*4) should be also substracted from the total walls surface.*

An assumption was made for windows, since no value was given. The windows are holes in the hard reflective surface of the walls, they cannot reflect and this assumption of total absorption reasonably holds.

Finally, we see a reverberation time of 0.58s with open windows, is that a good value? We know that RT of 0.5-0.8s is appropriate for speech and office spaces and RT of 1.2-2.5s is proper for music (or higher in some cases, e.g. opera). Hence, it depends on the case of the room and acoustic activities always. It should be very fine to have an RT of 0.58s inside such a normal-sized room.

**c)** Sabine's reverberation time is a handy formula that we use but has shortcomings, it depends on the asusmption of diffuese field, i.e. equal statistical energetic distribution for the energy of the reflected rays in a closed space. That cannot be always fulfilled, especially in small rectangular rooms which are the most common. Other indicators of acoustic performance can be loudness, strength (G), clarity of 50ms or 80ms ($C_{50}, C_{80}$), early decay time (EDT) and more (see lectures on RT). Those measures are used in the design of music halls for example, while for simple applications we rely on Sabine's RT, always with some uncertainty and space for errors.