METHODOLOGY STATEMENT

Project name **Impact of Rockfon acoustic products on overall learning, performance, privacy, health and well-being**
Client **Rockfon/ROCKWOOL**

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1. Introduction

As an independent external consultant Ramboll has carried out an investigation on the impact of Rockfon stone wool ceilings on overall learning conditions in educational buildings.

The objective of this study has been to identify and quantify the links between measurable acoustical parameters, the acoustical design of the rooms that supports the functionality of educational buildings and classrooms and the sales volumes for Rockfon stone wool ceiling tiles to educational buildings.

This is done by scanning and identifying relevant international scientific literature that shows clear proof for supporting acoustical parameters and fits to the functionality of educational buildings. Thereafter a calculation tool was developed which calculates the chain of impacts from products sold to achieved effect on students and the number of students affected.

This document aims to transparently describe Ramboll's method of the calculation and determination of the impact of Rockfon's acoustic products on the overall learning environment in educational buildings. It aims to both describe and summarize the utilized inputs and assumptions.

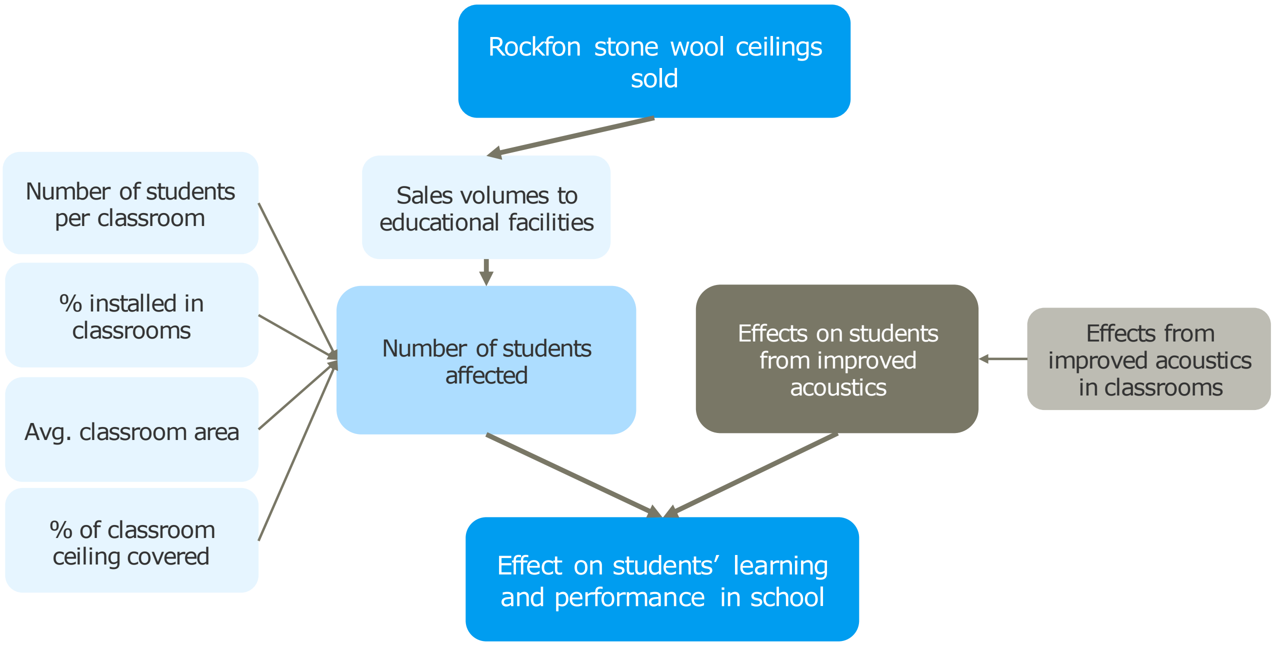
2. Methodology

To calculate the impact from installed Rockfon acoustical ceilings on students' learning and performance, a three-step process has been performed:

a) Identifying the chain of impacts from products sold to achieved effect on students
b) Quantifying the number of students affected
c) Assessing the effect on students from improved acoustics

The chain of impacts illustrates the chain of underlying factors that leads from sold products to an effect on students' learning and performance. The chain of impacts is illustrated below in Figure 1.

Figure 1: Chain of impact from sales volumes to effect on learning and performance



As illustrated in Figure 1 several underlying factors constitutes the chain of impact from sold Rockfon ceilings to an effect on students' learning conditions. Of these the two main intermediate elements are i) the number of students affected by the product and ii) the effect on students' learning and performance following an improvement in the acoustics of the learning environment. Therefore, in order to assess the effect from sold Rockfon ceiling elements i) and ii) needs to be known, i.e. quantified. The methodology of this is detailed in the subsections 2.1 and 2.2 below.

2.1 Quantifying the number of affected students

In order to assess the effect that Rockfon acoustical ceilings might have on students' overall learning and performance, the first of two steps are to quantify how many students will experience a better acoustic learning environment.

To quantify the number of students that will be affected by a year's sales of Rockfon ceilings, several intermediate calculations and inputs are needed:

a) sales volumes (m^2) to educational buildings, per region
b) the average number of students in a classroom
c) the average classroom size
d) the share installed in classrooms alone
e) the share of a classroom ceiling that is covered.

Calculations are carried out for one building application (stone wool ceilings) only. It has not been possible to distinguish between sales volumes for new buildings and building refurbishment since data on this has not been available. Underlying the calculations of c) - e) are a high degree of uncertainty due to only few available data sources and/or with high variability among estimates. Where possible, these calculations have been verified by Ramboll experts based on previous projects and experience.

The methodology used for each of the a) – e) estimates as well as the method of quantification, for each region, are described below:

a) **The regional sales volumes** for the years 2016-2018, which have been sold to educational buildings, are provided by Rockfon for each region (Far East Asia (FEA incl. China), Europe (incl. Russia and Middle East) and North America (US and Canada)). For the regions FEA and Europe, the share of sales volumes to educational facilities is estimated annually on country level and provided directly to Ramboll.

b) The **number of students per classroom** is calculated using different approaches for each region, due to data availability. The results are shown in the table below:

Table 1: Estimates of average number of students per classroom, per country region

Country region	Number of students per classroom (avg.)	Source
FEA	36	(Foster, 2016)
Europe	20	(OECD, 2019)
North America	23	(OECD, 2019), (Authier, 2014), (Hendricks, 2017), (McElroy, 2014)

For the region of Far East Asia (FEA) the number of students per classroom is calculated based on the average of 2014-estimates for secondary schools for China (49 students/classroom), Singapore (36 students/classroom) and Australia (25 students/classroom) (Foster, 2016). The estimated average is 36 students per classroom, but with a high degree of variability from the lowest (Australia) to the highest (China) values.

For Europe (incl. Russia) the number of students per classroom is calculated from OECD estimates of the countries with Rockfon sales (OECD, 2019). The estimate is calculated as the average of the number of students in primary and lower secondary education (2016) for each country, to an average estimate for the EU region at 20 students per classroom.

For North America the number of students per classroom is calculated as an average of the US estimate at 23 students/classroom (OECD estimates for primary and secondary education) and for Canada (24 students/classroom). The Canadian estimate is calculated from desk research for schools in various states[1] and for primary and secondary education (Authier, 2014), (Hendricks, 2017), (McElroy, 2014). The result is an average of 23 students per classroom.

c) The **average classroom size (m^2)** is calculated using one approach for the FEA and North America and another for Europe, due to variability in data availability. The results are shown in the table below:

Table 2: Estimates of the average classroom size, per country region

Country region	Average classroom size (m^2)	Source
FEA	113	(Newton International College, 2016), (Our school premises: Kingston International School, 2016), (Yam, 2017), (Wang L. , 2014).
Europe	144	from (Maesano & Annesi-Maesano, 2018)
North America	105	(Shield B. , Conetta, Dockrell, Connolly, & Cox, 2015), (Klatte, Hellbruck, Seidel, & Leistner, 2010)

[1] These states are: Alberta, Hard Cap, Quebec, Manitoba and British Columbia

The average classroom size for the FEA and North America region is calculated based on m^2 per student times the number of students per classroom (see step c) above). For FEA the m^2 per student is calculated based on case studies from China (Newton International College, 2016) and Singapore (Our school premises: Kingston International School, 2016), (Yam, 2017), (Wang L. , 2014). The result is an average of 2.7 m^2 per student, which is multiplied with the average of 36 students per classroom for FEA to an estimate of 113 m^2 for an average classroom size in FEA.

Using the same approach for North America, the m^2 per student is gathered from (Maesano & Annesi-Maesano, 2018), providing an estimate of 4.6 m^2 per student. This estimate is then multiplied with the average number of students per classroom from step b), resulting in the estimate of an average classroom size of 105 m^2.

For Europe, the average classroom size is calculated as the average of estimates from the literature on classroom sizes in the UK and Germany. For the UK the average estimate is found at 56 m^2 per classroom (Shield B. , Conetta, Dockrell, Connolly, & Cox, 2015) and for Germany 231 m^2 per classroom (Klatte, Hellbruck, Seidel, & Leistner, 2010). The result is an average across these two countries at 144 m^2 per classroom, but with a high degree of uncertainty due to the large variability in estimates. However, when taking the average across the two countries, the estimate is within the range of the estimates of the other two country regions.

d) The **share of Rockfon ceiling installed in a classroom** is calculated by firstly assuming that equal priority is placed on installing the product in classrooms as in the rest of the school area. Due to data availability, the approach of calculating the share installed in a classroom varies among country regions and will be described in turn below. The overall results are shown in the table below:

Table 3: Estimates used to assess the share of Rockfon ceiling installed in a classroom

Country region	Estimate	Source
FEA	0.01 classes per m^2 school area	(Sing Yin Secondary School: Wikipedia, 2019)
Europe	31 % of school area covered by classrooms	(New Middle School Building: Benjamin Franklin International School, 2019)
North America	0.08 students per m^2 school area	(Argon, 2003)

For FEA the number of classrooms per m^2 school area is estimated to 0.01, by dividing an estimate of school area of 6,503 m^2 with the schools 30 classrooms (Hong Kong (Sing Yin Secondary School: Wikipedia, 2019) times the average of 2.7 m^2 of classroom area per student (China and Singapore) (see c) above).

For Europe the school area, on average, covered by classrooms is estimated at 31 %, with a high degree of uncertainty. The estimation is based on area details from a school in Spain (New Middle School Building: Benjamin Franklin International School, 2019) which features a school area of 2,500 m^2, 15 classrooms and an average size of 52.2 m^2 of a classroom. This estimate for the EU region has been further verified by reviewing school projects that have been built in 2016 in Denmark, which confirms an area of about 30 % covered by classrooms.

For the US region the number of students per m^2 school area has been calculated to 0.1 students/m^2, by using estimates of school area divided by number of enrolled students for an elementary, middle and high school in the US (Argon, 2003).

e) The **share of a classroom's ceiling which is covered** by Rockfon stone wool acoustic ceiling is by Ramboll assumed to be 90 % based on Ramboll's experience and knowledge from educational project within the Ramboll Acoustics department. This means that 10 % of the ceiling area is allocated to lighting and air devices etc.

Combining the estimates for a) – e) provides the number of students, per country region, that the sold Rockfon ceiling will affect. The method for how the final number of students is calculated is detailed in steps below:

Calculating the number of affected students in FEA:
1. The number of products sold (m^2) in 2018 to the FEA region, is separated into volumes sold to education exclusively (step a)
2. The number of classrooms with the product installed is then calculated by multiplying the number of classes per school area (table 3) with the share of a classroom area that is covered (90 %) (step e).
3. The number of classrooms with installed Rockfon ceilings (step 2) is then multiplied by the avg. number of students (table 1) which results in the total number of 5,400 students attending classes with improved acoustics from the installed Rockfon stone wool ceilings.

Calculating the number of affected students in Europe:
1. The number of products sold (m^2) in 2018 to the European region, is separated into volumes sold to education exclusively (step a)
2. The amount installed in classrooms (m^2) is calculated by multiplying the share of classrooms (table 3) with the area of a classrooms ceiling which is covered (step e).
3. The number of classrooms affected is calculated by dividing the amount installed (step 2) with the average classroom size (table 2).
4. The number of affected students is calculated by multiplying the classrooms with Rockfon ceiling installed (step 3) with the avg. number of students per classroom (table 1).

Calculating the number of affected students in North America:
1. The number of products sold (m^2) in 2018 to the North American region, is separated into volumes sold to education exclusively (step a)
2. The number of students affected is then calculated by multiplying the sold volumes to education with the number of students per m^2 school area (table x) and the share of a classroom ceiling which is covered (step e).

The estimated of the number of students affected, in 2018, is 5,400 in FEA, 221,200 in EU and 112,100 in North America. The low estimate for FEA, relative to the other country regions, is due to a lower sales volume and hence school and classroom installations.

2.2 Assessing types of effect on students from improved acoustics

Several studies have shown that a decrease in reverberation time improves the speech intelligibility index which has a direct impact on improving the learning conditions for the students. Therefore, to specify the **impact on the learning environment for student's,** reverberation time is considered as the main acoustical parameter for this study.

The approach described in this study consists of the acoustical impact of Rockfon stone wool ceiling tiles compared to a reference situation:

- In case of new buildings, a classroom where no acoustic ceiling is applied
- In case of refurbishments, a classroom where either no acoustical ceiling is applied, or a ceiling with low absorption values

The impact of the acoustic products is expressed as the changes regarding the acoustic environment with respect to the reference situation. Since reverberation time is considered the main acoustical parameter, calculations of reverberation time in an average size classroom with acoustical properties as described above have been performed using the room acoustic simulation tool, Odeon.
The reverberation time (averaged over octave frequency bands 125 – 4.000 Hz) of the reference situation is 1,2 second, while the reverberation time in a classroom with Rockwool stone wool ceiling is calculated to 0,4 second.

These results have been used as a guide for comparison with the results that is presented in the scientific references to determine the overall impact of the reverberation time in classrooms with Rockfon stone wool ceiling. However, most studies do not investigate conditions with reverberation time below 0,5 s in classroom settings. It can be assumed that the lower reverberation time with Rockfon stone wool ceiling will provide better acoustic conditions than this study suggests. This approach is applied due to the underlying conservative evaluation regarding the impact of Rockfon stone wool ceilings on overall learning conditions in educational buildings.

Benefits from improved acoustics are based on reliable international research studies, mainly from European and North American articles. The developed links are documented, and the statements are based on a conservative approach, meaning that the most conservative data over various articles were used. The assumptions about quantities have been made well inside expected values of the concerned quantity.

The literature search resulted in a commented evaluation of the relevant articles and research results identified in relevant sources, including conference proceedings from several acoustic conferences, and scientific diverse journals on acoustics, indoor environment, human behaviour, working environment, wellbeing and health.

The literature review showed substantial evidence that ***improved acoustics in classrooms creates positively influences learning conditions for students*** (Klatte, Hellbruck, Seidel, & Leistner, 2010), (Kristiansen, Persson, & Lund, 2013), (Ljung & Kjellberg, 2008), (Peng, Wang, Lau, & et al., 2015), (Shield B. , et al., 2013), (Rasmussen & Guigou-Carter, 2016), (Bradley, 2014), (Wang L. , 2014)

3. About Ramboll

Ramboll is a leading engineering, design and consultancy company founded in Denmark in 1945. The company employs 15,000 globally and has especially strong representation in the Nordics, UK, North America, Continental Europe, Middle East and Asia Pacific.

With more than 300 offices in 35 countries, Ramboll combines local experience with a global knowledgebase constantly striving to achieve inspiring and exacting solutions that make a genuine difference to our clients, the end-users, and society at large. Ramboll works across the markets: Buildings, Transport, Planning & Urban Design, Water, Environment & Health, Energy and Management Consulting. www.ramboll.com

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