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Managing quartz exposure in the construction industry

FINAL REPORT OF RESEARCH PROJECT

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Abstract

This is the final report of the research project "Quartz exposure and its management in the construction industry" funded by the Labor Protection Fund in Finland, The Finnish Construction Workers Union and The Finnish Construction Industry. The report describes how to safely perform house construction and infrastructure construction work that exposes you to quartz dust. The present report is an abbreviated translation of a Finnish report containing good practices for the tasks studied. These good practices have since been finalized and published separately on the webpages of the Finnish Institute of Occupational Health and will be translated as well:

Kvartsialtistuminen ja sen hallinta rakentamisessa | Työterveyslaitos (ttl.fi)

To protect the health of those occupationally exposed to respirable quartz, most of the industries where quartz exposure is a problem in the European Union, signed in 2006 "The Agreement on Workers Health Protection through the Good Handling and Use of Crystalline Silica and Products Containing it" (NEPSI-treaty). In the treaty, the parties agreed on appropriate measures for the improvement of working conditions through the application of good practices. The construction industry did not join the NEPSI agreement even though there was an urgent need for similar measures and good practices to control construction workers' exposure to respirable quartz. The present report describes how to safely perform apartment building construction and infrastructure construction work that exposes you to respirable quartz dust. The starting point was to identify work tasks in which quartz exposure can be significant and to describe their safe execution so that exposure to both respirable quartz and respirable dust is at most low. To help with this, we also evaluated the effectiveness of dust control measures in reducing exposure.

The tasks studied pertained to the construction of apartment building frames, interior work phases in building repairs and in novel building projects, in addition to land infrastructure construction and demolition of buildings. Work tasks where exposure was low included construction cleaning, work management, installation of concrete elements, rebar laying, driving work machines equipped with cabin air intake filtration, and landscaping, in addition to some of the tasks in road construction. Excessive exposure, i.e. exposure exceeding the occupational exposure limit (OEL value, 0,05 mg/m^3), was found in all phases of construction. Excessive exposures were related to not using respiratory protection at all or to not using it for long enough after the dusty activity ceased. The work tasks in which excessive exposure was found were sandblasting, tasks assisting sandblasting, dismantling of facade elements, diamond drilling, drilling of hollow-core slabs, drilling with a drilling rig, priming of explosives, tiling, use of cabinless earthmoving machines, and jackhammering; regardless of whether the hammering took place in an underpressurized compartment or not. Correspondingly significant exposure (>0,02 mg/m^3) was found in e.g. the levelling of indoor walls and roofs, the spreading of railway ballast, and road construction (footmen).

The average exposure in these jobs was 0,032 mg/m^3 (n=148), with 10% of exposure estimates exceeding the OEL value. However, even though exposure to respirable quartz was thought to be high in most of the work tasks that were selected to be measured, in more than half of the tasks, the exposure was low, as the 60% percentile was well below 10 % of the current OEL, as was the median exposure (0,0031 mg/m^3). Even in those tasks where significant or excessive exposures were measured, it was possible to perform the work safely, following good dust prevention measures and, when necessary, by using respiratory protection suitable for the job. And on the other hand, in all tasks with generally low or negligible exposure, it is possible to be significantly exposed through the general air or by making bad choices in terms of dust control.

High general air concentrations were found especially in indoor work where the above-mentioned work tasks with high exposures was performed, and in few outdoor work tasks, e.g. in the vicinity of drilling rigs, crushers and earthmoving machines. On average, general air concentrations were 0,072 mg/m^3, with the median being 0,0024 mg/m^3 (n=88 kpl). Of the general air concentration measurements, 43 % exceeded 10 % of the current OEL. In indoor work, quartz dust concentrations in the general air were controlled e.g. by using equipment-specific local exhausts and/or water to control dust emissions, as well as by performing tasks in the right order, not simultaneously with work tasks associated with high dust emissions. Mobile air cleaners placed near dust emissions sources were shown to be effective as well, as was compartmentalization and negative pressure, and good cleaning and sanitation practices. The use and maintenance of the right type of respirators and the timing of their use were also keys to protecting workers from high dust concentrations in the general air.

Successful dust control in a construction project requires the seamless cooperation of all parties involved. Everyone, from the builder to the worker, has to take care of their own dust control tasks. In a construction project, the constructor's task is to guide and monitor dust control and cooperation work in practice, while the main contractor prepares a dust prevention plan for the construction site. Each employer should choose his work methods in such a way that no dust is generated or that it is generated as little as possible, in addition to instructing employees on dust prevention measures. Based on our measurements, more attention should be paid to controlling dust concentrations in the general air of indoor works. Especially to preventing the spread of dust and to the pacing of work tasks. When respirators were used, they were usually correctly chosen. Instead, deficiencies were repeatedly found in their use and maintenance. As in the maintenance of underpressure devices (dust extractors), execution of compartmentalization, and in the use of alternative work methods. And also, in the implementation of dust control measures, when it comes to e.g. matching exhaust vents to devices or choosing effective enough vacuum cleaners for the exhaust vents.

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1 Introduction

Crystalline silica has seven different crystal forms. In Finland you can be exposed mainly to quartz and, e.g., in the ceramics industry or in the production of refractory materials, also to cristobalite [1]. Quartz occurs e.g. in bedrock minerals, sand and rock materials. An estimated 12% of the Earth's crust consists of quartz [2]. Therefore, quartz is common in products and materials containing minerals, sand and rubble. In construction, these are e.g. concrete, cement, mortar, bricks, tiles, sand, stones and bedrock. Depending on the production temperatures, materials containing quartz can form amorphous silica (glass) or different crystalline forms, such as cristobalite or tridymite. The physical properties of crystalline silica and their insolubility in the lungs make them harmful when inhaled, depending on the particle size, causing e.g. silicosis and lung cancer. Since the lung changes affected by silicosis and usually also of lung cancer are irreversible and there is no effective treatment for them so far, all efforts must be made to prevent or reduce exposure of workers to silicon dust [3].

Although the health hazards associated with stone dust exposure, their causes, consequences, and means of prevention, have been known for a very long time, quartz exposure is still one of the biggest causes of health harm and increased risk of illness in many professions. In Finland alone, at least 50,000 workers are exposed to quartz in their work, with 0,2 ‰ of them per year officially contracting either silicosis or lung cancer derived from quartz exposure at work [4]. In order to promote the well-being of those exposed to quartz at work and to reduce the economic and human losses resulting from exposure, the most important sectors where quartz exposure is a problem in the European Union (EU), excluding the construction industry, signed in 2006 "The Agreement on Workers Health Protection through the Good Handling and Use of Crystalline Silica and Products Containing it" (NEPSI-treaty) [5]. The parties to the agreement were both employer and employee organizations covering e.g. foundry industry, mining industry, glass and ceramics industry, glass fiber industry, metal industry, and construction product industry. With the agreement, occupational hygiene limit values and exposure assessment methods for respirable quartz were harmonized in many EU countries. In this context, also the occupational exposure limit (OEL) in Finland was lowered from 0,2 mg/m^3 to 0,05 mg/m^3 [6]. And the sampling policy of the Finnish Institute of Occupational Health (FIOH) was changed to match the standards EN- 481 and ISO 7708 [7, 8], to comply with the method and particle size range agreed in the NEPSI-treaty.

In the first five years after the EU quartz agreement, work-related exposure to respirable quartz in our country fell sharply in the sectors that had joined the agreement. Nowadays, exposure has stabilized at a level, where exceeding the OEL value is significantly rarer than previously [4, 9]. Consequently, the 95 percentile of workplace measurements made by FIOH was 1,0 mg/m^3 in 2006 and 0,05 mg/m^3 in 2016, while the share of exposures exceeding the OEL value decreased simultaneously from 44 percent to 5 percent [4].

However, the reduction in work-related exposure would seem to apply mainly to industry sectors that signed the NEPSI-treaty, not to construction work. Construction work accounted for only 6% of the occupational hygiene exposure measurements made by FIOH until 2020, despite 2/3 of those exposed to quartz at work being construction workers [4, 9].

1.1 Controlling dust in building sites is a co-operative effort

The success of dust control in a construction project requires the seamless cooperation of all construction parties and that each party performs its own tasks in dust control. In Finland, the task of the developer is to guide and supervise dust prevention measures, and for this purpose the developer prepares a safety plan for the construction project. This document contains instructions and requirements regarding the elimination or reduction of exposure to dust and the prevention of its spread in the various works and functions of the construction project. The safety plan guides the planning, selection and implementation of dust prevention measures by the designers, the main contractor and subcontractors of the construction project. The developer updates these dust prevention requirements together with the designers, the main contractor and the subcontractors. The developer should also determine whether there is a need to carry out occupational hygiene measurements in the construction project, for example in jobs and functions for which there is no exposure information from previous measurements. The designers use design methods to eliminate dusty work phases, e.g. choose materials that do not release (harmful) dust, favor the use of compatible materials requiring as little on site machining as possible, and take into account the space required for possible central vacuum cleaners.

The main contractor prepares a dust prevention plan for the construction site, in which measures to prevent the spread of dust are defined for each work phase and task. The plan includes e.g. necessary compartmentalization and underpressurization, timing of work, local exhausts in machines and tools, and cleaning methods as well as the cleaning frequency. Filter requirements for dust removal and cleaning devices, as well as requirements for the use and condition monitoring of respirators should also be mentioned. In addition, cleaning and maintenance facilities for work tools, work clothes and personal protective equipment should be covered. Each employer should choose the work methods used in such a way that no dust is generated, or that it is generated as little as possible, taking into account the rules and instructions of the builder and the main contractor. And instructs its employees on dust prevention measures.

1.2 Legislation and the obligations of employers in Finland relevant to respirable silica exposure assessment

According to the Finnish Law on safety at work, evaluation of risks pertaining to work tasks is obligatory, and hence, also exposure assessment to respirable quartz [10]. Unless excessive exposure can be ruled out altogether or if it cannot be based on available data, risk evaluation necessitates exposure measurements. The need for occupational hygiene measurements and, with that, the investigation of exposure to respirable silica is also included in the Government decree on the safety of construction work and in the act on the list and register of those exposed to carcinogenic substances and methods at work (ASA register) [11-12]. In addition, the Government decree on the safety of construction work stipulates that on a joint construction site, both the developer's instructions and the main contractor's safety plans must provide instructions on the procedures for occupational hygiene measurements in the construction project.

At the end of 2019, a binding limit value (2xOEL value, i.e. 0,1 mg/m^3) was set for respirable silica in Finland in the Government decree on the prevention of work-related cancer risk (1207/2019), to correspond to the value set in EU directive 2019/130 based on cancer risk [13-14]. With this, the law on the ASA register was also revised, as a result of which those exposed to respirable quartz at work must be reported to the register. In spite of other legislation mentioned above, in practice, only with these measures was the Finnish construction sector broadly activated to the fact that quartz exposure of workers must be investigated and managed.

According to current practice, workers who are exposed to carcinogenic factors more than the so called background concentration are reported to the ASA register. In other words, if their quartz exposure exceeds what they would be exposed to without the job in question, registering is obligatory. In Finland, concentrations of respirable quartz in general air have not been published, and there is very little information on background concentrations in the rest of Europe. More measurements have been made in the USA. The concentration of respirable quartz in US metropolises ranges from 0,0011 to 0,0088 mg/m^3, with an average of 0,0032 mg/m^3 [15]. In measurements made in 1991 in the vicinity of a sand quarry in Monteray, the concentration of respirable quartz was 0,0011-0,0013 mg/m^3 [16]. In one similar measurement made by FIOH, the concentration was 0,00020 - 0.00023 mg/m^3 (unpublished data). According to the US Environmental Protection Agency (EPA), 0,0050 mg/m^3 is a low enough concentration to protect citizens from the harm of respirable quartz [17]. However, some US states have stricter health-based maximum concentrations for respirable quartz in ambient air. For example, for long-term exposure in Texas it is 0,00027 mg/m^3, in California 0,0030 mg/m^3 and in Vermont 0,00012 mg/m^3 [18]. In Finland, the practice is that employees are reported to the ASA register if they are estimated to be exposed to more than 0,0050 mg/m^3 respirable quartz at work, i.e. 10% of the present OEL value. Based on the above, this is a level that is rarely exceeded even in urban environments. And this is also a level that, according to current knowledge, is not associated with mentionable health hazards, because the lungs are able to remove small concentrations of quartz to the ciliary area, from which they are removed via the mucus elevator [19].

In addition to ASA registration, according to Finnish legislation, the employer must organize health checks for workers in work tasks that are associated with special risks of illness [20]. With regard to respirable quartz dust, this means that regular monitoring of the state of health must be arranged for workers who are exposed to respirable quartz to the extent that, according to current knowledge, causes a specific risk of illness. Meaning in practice that quartz exposure is significant, i.e. more than 0,02 mg/m^3 as a working career average [21-24].

1.3 Exposure classification

As mentioned, the on principle health-based OEL for quartz and other respirable silicon dioxides set by the Finnish Ministry of Social Affairs and Health is 0,05 mg/m^3, whilst the statutory exposure limit is 0,1 mg/m^3. Finnish OEL values are values set for air pollutants in the workplace, which "the employer must take into account in the investigation and assessment of work hazards and in the planning of the work environment, when evaluating the cleanliness of the workplace air, the exposure of employees and the significance of the measurement results" [6]. The limit value, however, is not health-based, but it is a statutory limit that should not be exceeded in terms of average exposure over the course of a working day. The OEL values are basically health-based, but when setting them the seriousness of the health damage caused by the exposure is taken into account, as well as the level that is technically and economically possible in the workplace with current technology [6].

In the present study a FIOH exposure classification was adapted to respiratory exposure to quartz and respirable dust, with the difference that the limit for significant quartz exposure was lowered from 50 % to 40 % of the OEL (Table 1) [25]. The basis was that the EU risk assessment committee has estimated that < 40% of the OEL, as a working career average concentration, corresponds to a low risk level for silicosis [21]. And because in most risk assessments dealing with the career-long quartz exposure associated risks, a concentration corresponding to the OEL is associated with an increased silicosis risk [22]. Analogously, cumulative lung cancer risk estimates often end up between 0,04-0,05 mg/m^3 for a level of low cancer risk [23-24].

In the case of respirable dust, the results were compared with the OEL value of respirable cement dust (1 mg/m^3), because the effects of chromates and quartz are not taken into account in its basis and because many - although not all - of the dusts we measured on construction sites are quite comparable to cement dust for inst. in their composition, alkalinity and physiological effects [26-27]. This is a higher concentration than the FIOH target level for general respirable dust (0,5 mg/m^3), but lower than the corresponding OEL's in some EU countries (2,5-5 mg/m^3) [28-30].

Table 1 a. Classification of quartz exposure

Exposure (mg/m$_3$)	% of OEL$_{8h}$	Significance of exposure
< 0,005	< 10 %	Low
0,005-0,02	10-40 %	Moderate
0,02-0,05	40-100 %	Significant
0,05-0,1	> 100 %	Excessive
> 0,1	> 200 %	Exceeds statutory exposure limit

Table 1 b. Classification of exposure to respirable dust

Exposure (mg/m$_3$)	% of OEL$_{8h}$	Significance of exposure
< 0,1	< 10 %	Low
0,1-0,5	10-50 %	Moderate
0,5-1	40-100 %	Significant
> 1	> 100 %	Excessive

1.4 Real-time monitoring of respirable dust and quartz

Direct reading instruments are available for real-time monitoring of exposures to respirable dust. Some companies use these to monitor exposures from continuous processes e.g. in the loading or packaging of finished products. These devices work on the principle of light scattering, but they will not identify the composition of the dust [34], which is why it is challenging to reliably assess respirable quartz exposure using real-time monitoring of respirable dust mass concentrations. Even when the measurement is done from the worker's breathing zone, which is possible with some instruments. As the quartz content of construction dust varies greatly depending on the source of the dust, so will the accuracy of direct reading instruments. For example, the quartz content in granite and concrete is at most 30%, in limestone less than 1%, in sand more than 90%, in plasters usually less than 1%, in cement below 20%, in clay 5-50% and in foam glass <1-5% [5, 35-37]. Considering that airborne dust in any given construction site will, depending on the work tasks performed, originate from a variety of differing sources, a uniform correlation coefficient may be challenging to use in converting dust concentrations to quartz concentrations in construction sites. It has been suggested, however, that the internal filter collecting inhalable dust present in some direct reading instruments be analysed for both dust and quartz contents, to get a reliable calibration coefficient for each day dust is collected [34]. This is a valid possibility, provided the instrument has been used to assess personal exposure, even though it may be easier and more accurate to withdraw personal samples with the methods suggested in the NEPSI agreement and ISO-standards.

1.5 Control of general air respirable dust concentrations

Indoor construction work is often done in poorly ventilated premises, which is why high respirable quartz contents in the general air may in many professions be major source of exposure. Including in work tasks, that do not generate quartz dust per se. According to the Finnish Government Regulation on the safety of construction work, dust must be removed by air conditioning, targeted removal (e.g. tool specific exhaust vents) or other appropriate measures [11]. If necessary, the spread of dust must be prevented by shielding dusty work areas by protective walls. With the shielded area underpressurized to yield a sufficient pressure difference to inhibit spread of dust, as well as an air exchange ratio of, at the minimum, 6 h^{-1} [38]. In Finland, compartmentalization and negative pressurization of the premises is, however, most often not possible in conventional work, due to economic constraints. For instance, our partners and the representatives of the construction sites we investigated did not consider negative pressure to be a realistic option in most conventional interior work phases, because according to their estimation, it would substantially increase work and heating costs.

Recyclable air cleaners equipped with HEPA H13 filters may be a good way to supplement dust control, based on experience gained from Swedish construction sites, when they are used in confined dusty departments, together with machine-specific exhaust vents and possibly also with water to control dust emissions. On the condition, however, that they are placed as close as possible to the dust source [33, 39]. Consequently, in this project, we tested the effectiveness of air recirculating mobile air cleaners to control dust concentrations of general air in dusty, compartmentalized work areas. An alternative in many jobs would be the use of water to bind dust and prevent emissions, but it is often not an accepted option in indoor building. Nonetheless, compartmentalization coupled with underpressurization still remains the only viable option in many renovation demolition works and other work phases, where dust production is high [33].

A more effective means to control dust concentrations in general air is to limit emissions at the source, before they spread to the surrounding air space. Hence, we also wanted to test means of dust control in two work tasks critical with respect to dust emissions to the general air, the first being the mixing of mortar indoors and the second one the use of drill rigs outdoors.

1.6 Aims of the study

Since most domestic construction companies have not estimated quartz exposure of workers prior to 2020, e.g. as part of statutory risk assessment, construction employers often do not have sufficient data to assess who they should report to the ASA register and in which tasks the statutory limit value or OEL value may be exceeded [4]. And that's also why it's challenging in many, if not most, construction companies to decide which employees should be included in occupational health care health monitoring. These are considerable practical problems in an industry where tens of thousands of workers are potentially exposed to respirable quartz. This study addressed these needs. The starting point was to identify work tasks where quartz exposure can be significant or excessive and to give instructions on their safe execution so that the exposure can be kept at a low or even negligible level (table 1). To help with this, the project also evaluated the effectiveness of various dust control measures to reduce exposure. In the framework of this study, the applicability of direct-reading dust measurements to the assessment of respirable dust and quartz contents in the general air was also evaluated. Furthermore, the goal was to list tasks where occupational health care health monitoring and/or ASA registration come into question.

2 Methods

2.1 Selection of work tasks to be measured

A survey aimed at the project's participants was used to support in the selection of construction work tasks associated with significant or excessive respirable quartz exposure. In addition to the executors (FIOH, Tapaturva Ltd and Lotus Demolition Ltd), the participants were the Confederation of Finnish Construction Industries RT, the Finnish Construction Trade Union, the Regional State Administrative Agency (work-place inspectorate), and the five companies participating (see below). Based on the survey, a list of work tasks to be investigated in different phases of new and renovation construction was drawn up: foundation and frame phases of new construction, yard work, interior work phases in the renovation and novel construction of apartment buildings, facade work, demolition of buildings, infrastructure construction and concrete waste and stone crushing (pulverization). Selections were refined as the project progressed, while planning measurement visits in cooperation with the construction sites, and based on the information gathered at the construction sites.

2.2 Sampling sites

A total of 58 construction sites were visited on 63 different days between 1 January 2021 and 31 September 2022. The exposure to respirable quartz and dust during the working day as well as during dusty work phases was measured for a total of 150 workers yielding 300 samples for the analysis of respirable dust and as many for the analysis of respirable quartz. The general air concentration of respirable dust and quartz was estimated with the help of a total of 88 collected stationary samples and, in addition, with parallel samples using direct-reading instruments from 20 construction sites. The measurements were fairly evenly distributed among the five companies that participated in the project from the beginning, i.e. NCC Finland Ltd and Hartela Ltd (construction of new apartment buildings), CONSTI Ltd (renovation of residential and public buildings as well as office buildings), Destia Ltd (road and infrastructure construction, stone breaking plants), and Lotus Demolition Ltd (demolition of buildings). In addition, two additional companies were recruited to provide exposure measurement sites for the study: Purkupiha Ltd and Mevaset Ltd (mobile concrete crushing plants).

In addition to exposure measurements of dust generating work tasks performed on actual building sites, the effectiveness of dust control measures was measured when drilling with drilling rigs, in the use of air recirculating mobile air cleaners, and in mortar mixing points. Furthermore, task-specific exposure was monitored while following different types of dust and exposure prevention measures, including compartmentalization and underpressurization, machine-specific exhaust vents and irrigation, in addition to respiratory protection.

2.3 Measuring strategy

Many of the dust-producing tasks in construction require the use of a respirator for part of the day and sometimes for the entire workday. In each workplace we studied, our goal was to find out both the average exposure of the employees throughout the working day and the exposure concentration during dusty work tasks requiring respirators. For this reason, two cyclones collecting respirable dust were hung in the breathing zone of workers. The air sampling pump of the first sampler was on for the entire work shift, yielding the average exposure concentration throughout the workday. To the second sampler, air was sampled only when the worker was wearing a respirator. If a respirator was not used in the work in question, the pump for this second sampler was started whenever, according to the researcher's assessment, a respirator should have been used. By taking into account the assigned protection factors of the respirators used, we were able to collect the following exposure-describing results:

1. Exposure concentration during the working day
2. Exposure concentration in dusty work phases
3. Average exposure throughout the working day

and in situations where protection was not used also:

4. Average exposure throughout the working day, if a respirator suitable for the job had been worn during dusty work phases.

In addition to employee specific samples, samples describing the general air concentration were also collected from stationary measurement points at each workplace. These samples were collected from a height of approx. 1½ meters, usually from the same floor, department or apartment where dust-emitting work was carried out. In the case of outdoor work, general air samples were taken from the cabins of work machines and e.g. from blasting sites, earthmoving sites, green building sites, road construction and rail sites, from places where workers were exposed to respirable quartz through the general air.

Direct measurements for the assessment of quartz dust exposure had been proposed to the partner companies of our project by several companies that perform commercial workplace measurements. Therefore, in the present study, the concentrations of respirable dust in the general air were measured at 20 different work sites from the same measurement points, both with direct-reading particle counters calibrated for mass concentrations and simultaneously with methods compliant with NEPSI agreement and

ISO standards [5]. The samples collected by using sampling pumps and cyclones to filters were analysed for respirable quartz in addition to respirable dust, enabling evaluation of the applicability of direct-reading instruments for the assessment of respirable quartz dust concentrations in the general air.

2.4 Sampling and analysis of samples

Sampling of respirable dust was performed as described in CEN and ISO standards [7,8]. Briefly, airborne respirable dust samples were collected on 3,7 mm mixed cellulose ester membrane filters (Millipore AAWP037, 0.8 μm) using SKC GS-3 nylon cyclones. The flowrate of sampling pumps was calibrated with an accuracy of ± 5 % to comply with the respirable fraction of GS-3 cyclones (2,75 dm^3/min). Samples were collected either from the breathing zone of workers or from stationary points at a height of circa 1,5 m. Sampling was continued for a minimum of 4 h, usually close to 8 h, to estimate the average 8 h exposure of workers.

Samples containing calcite, i.e. most samples withdrawn, were treated with HCl prior to analysis. Namely, these samples were placed in a filtering funnel (pore size 0.5 μm, diameter 25 mm) using tweezers. 10 cm^3 of 9 % HCl and 5 cm^3 of 2-propanol were added and the sample filtered with the help of a vacuum pump after 5 min. The filter was washed twice with 15 cm^3 of ionized water and left to dry over night in porcelain crucibles using tweezers. Crucibles containing the dried samples were covered and ashed (2 h, 600 °C). Ca. 300 mg of oven dried (110 °C, 24 h, stored in a desiccator) and mortar ground KBr of infrared quality was added to the crucibles, after which the sample was transferred to mortars using wooden spoons and camel hair brushes. The samples were ground with the help of a pestle under a heat generating lamp. Lastly, the samples were transferred to a pellet pressing platform and the pellets were pressed with standard technology, using a Specac pellet press. Blank samples and control standards were prepared in an identical way.

Samples and standards were measured as described in NIOSH method 7602 [31]. The IR spectra was measured in absorbance mode. The pellet was scanned from 1000 cm^{-1} to 600 cm^{-1} and the peaks 775 and 800 cm^{-1} were used to identify quartz. Quantification was based on the absorbance (peak height) at 800 cm^{-1}, using the mean of four consecutive measurements. If the variation of the four measurements exceeded 3 times the standard variation from 60 random validation samples, the KBr tablet was reground, repressed and remeasured. The quantitative limit of detection was 2,0 μg/sample. If the limit of quantitation was not met, the result was depicted as < 2,0 μg. These results (21 %) were treated as 2,0/2 μg in the statistical calculations. If the result exceeded the linear range of the analysis (200 μg/sample), the sample was reground and diluted with KBr before remeasurement.

2.5 Direct-reading measurements of general air

Particle concentrations were measured in the general air as mass concentrations using optical particle counters (Grimm 1.108 and Grimm 11-C, Grimm Technologies, Germany). Grimm model 1.108 measures particles with an optical diameter of 0,30-20 µm with 15 channels, while model 11-C measures particles in the size range 0,265-34 µm (optical) using 31 channels. The particle analyzers record the particle concentrations in the air by particle size class every six seconds. The devices are initially calibrated to produce mass concentrations with standard dust (Arizona dust). The particle counters have internal filters that collect inhalable dust during the measurement period (cellulose ester, ⦰ 47 mm, pore size 0,8 µm, Millipore AAWP047M). The filters were weighed and the results were corrected after the measurements with the help of these weighing results. In this way, the result obtained with regard to the respirable fraction better correspond to the actual mass concentration of the dust measured.

2.6 Effectiveness of selected dust control measures

Dustcontrol DC AirCube 2000 cleaners (Dustcontrol Ltd, Norsborg, Sweden), equipped with HEPA H13 filters, and with an air flow-rate of 1 800 m^3/h were used in intervention measurements. i.e The same indoor work was performed during day one without using the cleaners and on day two with the cleaners. In the tests, the air cleaners were placed within 1-2 m of the dust source, with the air inflow directed towards the source. The results of such parallel measurements in the levelling of interior walls and roofs, as well as in indoor demolition hammering, were modelled using an equation by Ganser and Hewet as adapted by Pagels *et al.* [32-33] to assess how many comparable cleaners were needed in each situation to lower general air respirable dust and quartz concentrations and, hence, exposure of workers to low, or at the most, moderate levels (equation 1):

$$V\frac{dC}{dt} = S - C(t)\,x(Q_{vent} - CADR_{air\ cl.} + \ v_d A) \qquad (1)$$

where,

$CADRI_{air\ cl.}$ = Clean air delivery rate of air cleaner(s) in a room, assuming perfect mixing of air (m^3/s)

V = Volume of air space (m^3)

Q_{vent} = Ventilation rate in the premise (m^3/s)

S = Dust or quartz generation rate of the source (mg/s)

C = Respirable dust or quartz concentration in the premise mg/m^3)

v_d = Deposition rate of particles to surfaces (m/s)

A = Surface area of the premise (m^2)

t = Time elapsed since starting the cleaner (s)

In terms of dust control, the most effective way is to remove the generated dust at its source. Therefore, we also wanted to test the effectiveness of controlling dust emissions in the mixing of mortar with a mobile air cleaner. The cleaner had an air flow of 1300 m^3/h and was equipped with air flow directing side screens and a M-class filter (IEC 60335-2-69, Camu D2, Consair, Helsinki, Finland, Fig. 1). These measurements were done at an actual indoor work site with minute to neglible ventilation.

In addition, for the same purpose we tested an exhaust vent (Bad-Dust Oy, Helsinki, Finland) attached to a mixer and connected to a Dustcontrol DC-TROMB 400 vacuum cleaner with an air flow of 300 m^3/h as measured from the exhaust vent (Fig. 2). The vacuum cleaner was equipped with an HEPA H13 filter. These measurements were done in a test chamber with a ventilation rate of 0,7 h^{-1} and a surface area of 27 m^2, using a Flex R 503 FR, 530 r/min blender with a blade length of 680 mm (Steinheim, Germany, Fig. 2).

Figure 1. Use of a directed air cleaner in the mixing of mortar.

The drilling of shot holes and grooves at blasting sites can be associated with excessive exposure of the driller as well as other workers working near the drilling rig. As we did not come across effective enough dust control measures on actual working sites, we decided to test dust prevention measures related to drilling in field tests using a Sandvik Mining DINO DC420Ri top impact drilling rig, equipped with 40 l water container

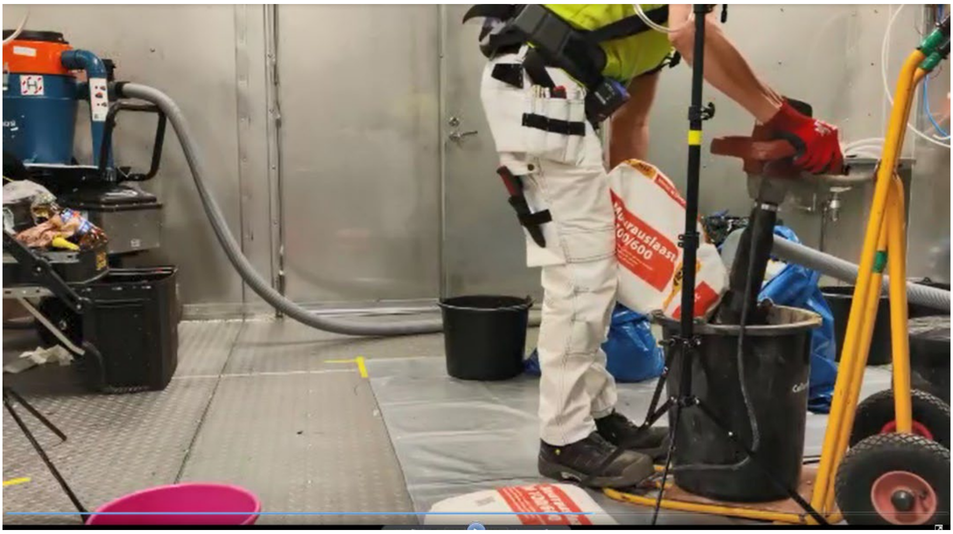

Figure 2. Testing an exhaust vent attached to the blender and connected to a H-class vacuum cleaner.

(Sandvik AB, Sandviken, Sweden). The water supply in wet drilling was adjusted to 0,4in. The diameter of the drilling holes were approx. 60 mm. The average concentration of respirable dust and quartz was measured at stationary measurement points and in the driller's breathing zone while drilling boreholes for approx. 3 h: 1) Without water use and without attaching flexible plastic tubes (socs) to dust separators, directing dust emissions to the ground as opposed to release of dust above ground; 2) Without water use, but with socs attached to front and rear separators; 3) With socs attached to separators and with water supply (Figs. 3-4).

Figure 3 a. Drill rig back separator with sock

Figure 3 b. Front separator (cyclone) with sock

Figure 3 c. Water supply adjustment of drill rig (ca. 0,4 l/min)

Figure 4. Measuring quartz dust emissions of a drilling rig in a test field.

3 Results

3.1 Work-task specific exposure

The work tasks that were selected to be investigated were those where quartz dust exposure was estimated to be the highest. In these jobs, the exposure to respirable quartz was on average 0,032 mg/m^3 and the proportion of those exceeding 10 % of OEL (ASA registering limit) was 38%, with 10% exceeding the OEL (Table 2). However, in more than half of the tasks, the exposure was negligible to low, as the 60% percentile was below the ASA registering limit, as was the median exposure (Table 2). Work task specific exposures to respirable quartz, taking in to account the use of respirators and the assigned protection factors of respirators used, are shown in Figure 5. Estimates of task specific exposure ranges based on the measurements are listed in Table 8 (App. 1). As expected, estimates of work task specific exposure ranges are highly dependent on the adapted dust prevention measures including ventilation, water use and the use of tool specific exhaust vents, as well as on the use of respirators and the duration of respirator use. In addition, the timing of work tasks with respect to the dust emission potential of simultaneously performed tasks is key in preventing exposure of (Table 8, Appx. 1). Most importantly, just as tasks potentially producing high amounts of respirable quartz dust can be carried out safely, it is also apparent that one can be exposed excessively in work tasks where the dust emission is normally low or even negligible, by making wrong choices as pertains to working methods or, for instance, to the timing of the work task in relation to other work tasks with much higher dust emissions (Table 8, Appx. 1).

Table 2. Estimated quartz exposure in work tasks

Nr of workers	148
Mean (mg/m^3)	0,032
Median (mg/m^3)	0,0031
95 % percentile (mg/m^3)	0,072
60 % percentile (mg/m^3)	0,0040
Above 10 % of OEL (%)	38
Exceeding OEL (%)	10
Exceeding statutory exposure limit (%)	4

In terms of exposure, other dust-producing tasks performed nearby or on the same department or floor are key, because concentrations in the general air can exceed exposure in many work tasks (Tables 2-3). For this reason, in indoor work in departments where very dusty tasks are performed, all those visiting the department for even a short time must wear at least an FFP3 respirator. And those who work there for a long time must wear a breathing assisted TH3P/TM3P class respirator. This also applies when the compartment is pressurized. Such tasks include, for instance, jackhammering, hollow-core slab drilling for the purpose of drying slabs, diamond sawing and drilling, floor grinding, and levelling of inner walls and roofs (Table 8, Appx. 1).

Table 3. Quartz content of general air on construction sites

Nr. of samples	88
Mean (mg/m^3)	0,072
Median (mg/m^3)	0,0024
95 % percentile (mg/m^3)	0,20
Above 10 % of OEL (%)	43
Exceeding OEL (%)	13
Exceeding statutory exposure limit (%)	10

Excessive quartz exposures, i.e. exceeding the OEL, were measured in all phases of construction (Table 4). Namely in sandblasting, diamond sawing and -drilling, demolition hammering and drilling of hollow core slabs and charging holes (Table 4). Excessive exposures were mostly related to not using respiratory protection at all, or to not using respirators for long enough after ceasing a dusty activity, or to protect oneself against high concentrations in the general air (Table 4). If, for example, sawing or diamond sawing is carried out in an underpressurised section, the respirator can be removed while staying there no earlier than one hour after the cutting or sawing has ended, assuming that the exhaust ventilation air flow follows recommendations [38] and no other dusty work is carried out in the section, such as e.g. removal of demolition waste with a bucket loader (see Fig. 6).

Just as the excessive exposures mentioned, significant exposures (>0,2 mg/m^3) present during the span of a working career are associated with an increased silicosis risk. Significant exposures were found e.g. in the levelling of indoor walls and roofs, the spreading of railroad ballast and in road construction (footman) (Fig. 5, Table 8 Appx. 1). High concentrations in the general air were measured e.g. in under-pressurized departments, where partition walls or suspended ceilings were demolished by a robotic jackhammer, in the pulverization of concrete demolition waste, in gravel pits near crushers, in the loading and spreading of railroad ballast, in blasting sites near drilling rigs, in hooded facade work and in departments where jackhammering, hollow slab drilling or diamond sawing and diamond drilling were carried out (Table 8, Appx.1).

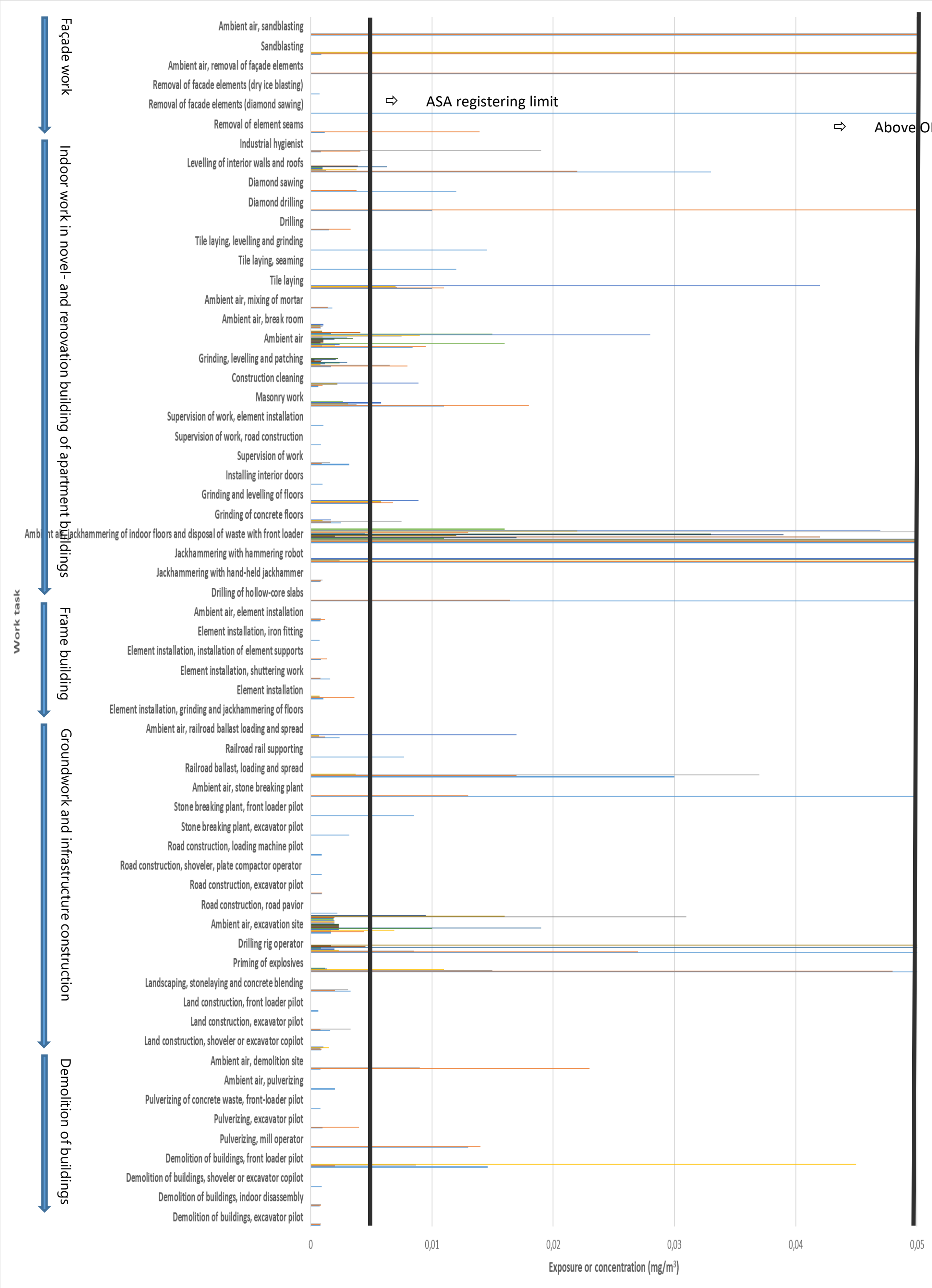

Figure 5. Respirable quartz exposure in building work tasks, taking into account the use of respirators.

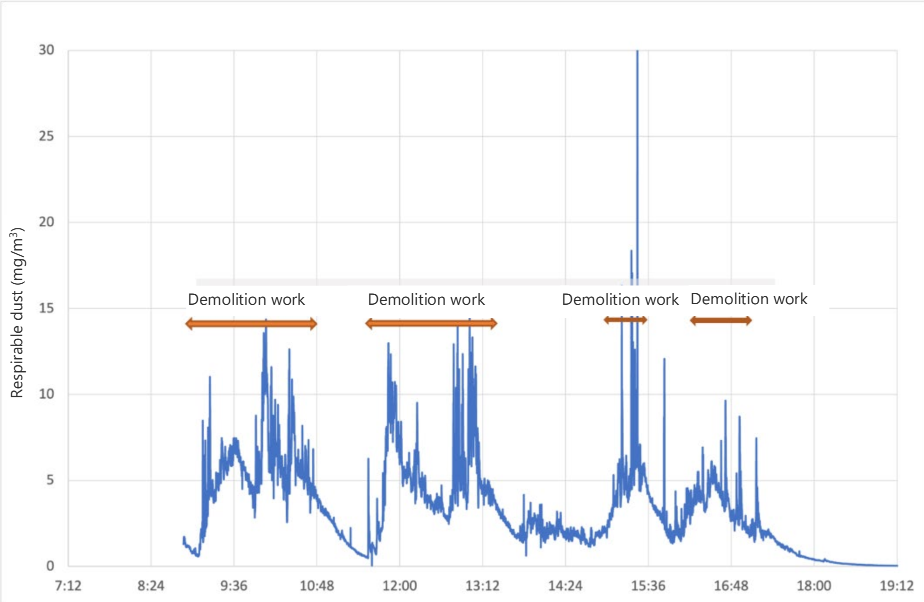

Figure 6. Respirable dust concentrations in an underpressurized area during and after jackhammering. The concentration reaches safe levels two hours from ceasing jackhammering.

Based on our measurements, work tasks that expose you to low or moderate quartz concentrations include e.g. work management, element installation, rebar placing, driving work machines equipped with cabin air intake filtration, landscaping and construction cleaning, as well as several tasks related to road construction (Fig. 5). However, as previously mentioned, in all these tasks you can be exposed significantly, and sometimes even excessively, by making wrong choices (Tables 4 and 8). Management can be exposed, for example, by spending longer periods of time without a respirator in departments or on floors where dusty work is done. Element installers can be exposed by e.g. multiple drilling to install support bars and post-installed reinforcing bars for concrete elements without respiratory protection. The drivers of work machines can similarly be significantly exposed to respirable quartz by keeping the cabin windows open or by spending longer periods outside the cabin when, for example, charging holes are drilled, dry crushed concrete waste is pulverized at demolition sites, dry substrates are levelled with plate compactors, or dry, dusty quartz-containing materials such as foam glass, sand or demolition waste are moved. Green builders, on the other hand, can be exposed to quartz e.g. when mixing concrete without a respirator or when using plate compactors to settle pavement seaming sand or to even sand before laying pavement stones. Building cleaners can also be significantly exposed if they work in premises where dusty work is done or if they use a brush instead of a cleaning squeegee to pile up larger waste. And also, when emptying vacuum cleaners that do not have closable dust bags. In building cleaning, as in most other interior jobs, it is therefore important how other jobs are paced in relation to cleaning. And, on the other hand, what choices are made to control dust in the work itself. In interior construction sites, cleaning the floor or department should be done, at the earliest, the next day after the dusty work is finished (Table 8, Appx. 1).

For these reasons, when considering what employees to list to the ASA register, no occupation could be excluded on principle. Nor was it possible to arrange work tasks in order based on the significance of exposure. The construction site's task specific and work phase specific dust prevention plans, as well as practices and personal choices ultimately determine the extent to which each worker is exposed to respirable quartz (Table 8, Appx. 1). In terms of avoiding exposure, the most important thing is not the work task performed, but how the work is done and what dust prevention measures are followed. For example, in many outdoor jobs such as the demolishing of buildings or the levelling and moving of soils, the use of water determines whether the foremen, shovellers or landscapers are exposed to respirable quartz. Similarly, in many indoor jobs, in addition to the use of water, exposure may depend on ventilation rate, the use and effectiveness of equipment specific exhausts, the timing of the work in relation to other dusty jobs and the use of respirators and the timing of their use.

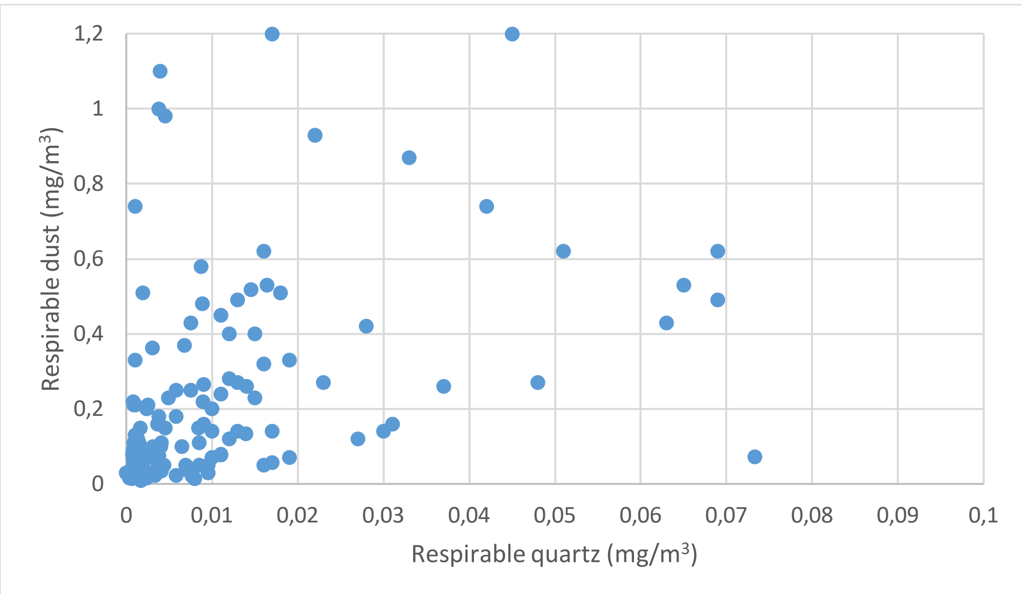

Figure 7. Exposure of workers to respirable dust and respirable quartz in the work tasks studied.

Table 4. Excessive exposures to respirable quartz and dust on the construction sites

Phase of construction	Work task	Quartz exposure, (mg/m³)	Dust exposure (mg/m³)	Reasons for exceeding OEL
Facade work	Sandblasting, helper	0,21	5,0	No respirator
	Sandblasting	0,83 0,073	13 0,073	Respirator used only during active blasting.
	Removal of facade elements (diamond sawing)	0,081	2,05	No respirator
Demolition	Excavator pilot	0,045[1]	1,2	High dust content in general air (cabinless excavator).
Indoor work, novel- and renovation sites	Diamond drilling	0,051	0,62	No respirator. Water was used during diamond drilling but not when drilling anchor holes for diamond drill rig.
	Jackhammering of interior roofs	0,070	9,4	Respirator in use only when actively jackhammering.
		0,058	1,4	No respirator
		0,1	1,8	No respirator
		0,61	12	Respirator in use only when hammering.
	Drilling of hollow-core slabs	0,065	0,53	Respirator in use only during active drilling.
	Tiling	0,042[1]	0,74	No respirator during shaping of tiles with an angle grinder and drilling of runs through tiles with a diamond drill
Land and foundation work, infra-structure construction	Drilling of charging holes	0,069 0,069 0,17	0,62 0,49 1,1	No respirator. Water was not used to suppress dust emis-sions and dust separa-tors lacked socks.
	Priming of charging holes	0,063 0,048[1]	0,43 0,27	Primers worked downwind and close to the drilling rig.

[1]Upper limit of result including method uncertainty (± 27 %) exceeds OEL.

3.2 Exposure to respirable dust vs. respirable quartz, estimated using traditional sampling and real-time monitoring

As expected, the ratio of respirable quartz to respirable dust in our exposure measurements varied in many cases by more than 100%, depending on the origin of the dust (Fig. 7). Hence, a single correlation coefficient could not be applied in converting concentrations of respirable dust to quartz in the construction sites we investigated. In the present study, the mass concentrations measured by the direct reading devices used were calibrated using the inhalable dust collecting internal filters, assuming the mass to particle count correlation was independent of particle size. The resulting respirable dust mass concentrations in the general air of the construction sites as estimated by real-time monitoring was compared to respirable dust and quartz measurements by traditional methods, from the same exact locations. The Pearson correlation coefficient of the parallel respirable dust measurements was relatively poor (0,88) and there was a statistically significant difference between the methods (Student's two-tailed t-test P_{025} = 0.52). The magnitude of the results using the different methods were, however, of fairly equal levels (Fig. 8). Hence, the tested direct reading devices are well suited, for example, for evaluating the spread of dust in the general air or outside a compartmented area, as well as for comparing and evaluating the effectiveness of dust control measures. Or to exclude exposure given the respirable dust concentration in some building site premises are, for instance, below 0,005 mg/m^3. Which is, unfortunately, seldom the case when working indoors in construction sites. Exposure to respirable dust could not, however, be determined reliably with the tested device, and even less the exposure to respirable quartz, which involves much more uncertainty factors, with parallel measurements yielding an 0,46 Pearson correlation coefficient (Fig. 9).

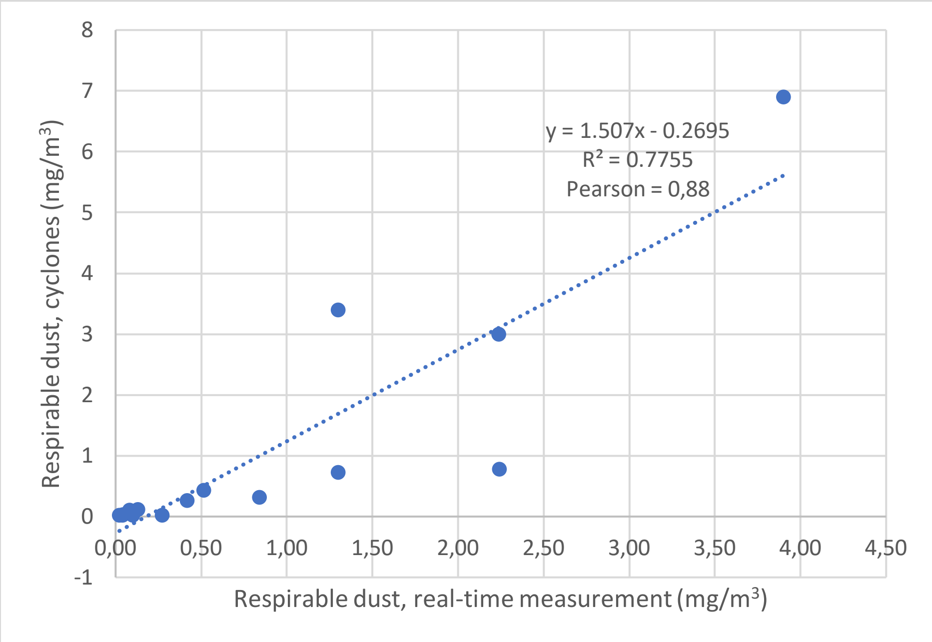

Figure 8. Respirable dust concentrations as measured from samples collected to filters using cyclones (EN 481, ISO 7708) and by real-time moniroting.

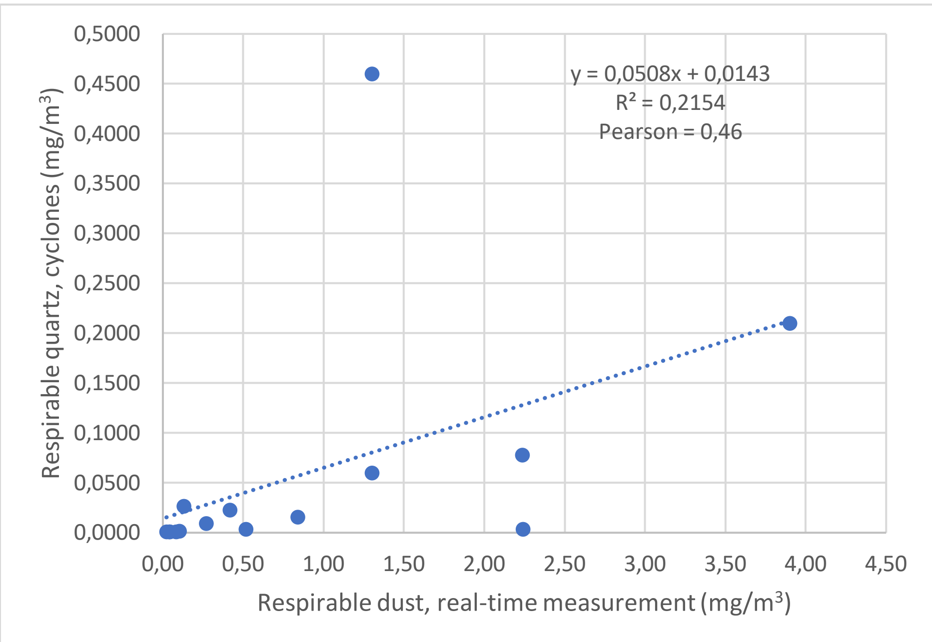

Figure 9. Respirable quartz concentrations as measured using analysis of samples collected to filters using cyclones (EN 481, ISO 7708) and respirable dust concentrations by real-time monitoring.

3.3 Respirator use and exposure

The construction tasks where quartz dust exposure was thought to be the most significant were pre-selected for the present measurements. In many of the studied tasks, respirator use is necessary in dusty activities and sometimes throughout the working day. However, in many of the tasks requiring the use of a respirator, the respirators were not used for long enough periods to protect from exposure through general air outside dusty activities, such as active drilling, grinding or demolition hammering. Consequently, in those jobs where respirators were used, they reduced the respirable quartz exposure, on average, by not more than 50% (median 58%). i.e. When using respirators, the exposure was on average half of what was the average respirable quartz concentration measured during the working day in the worker's breathing zone (Fig. 10).

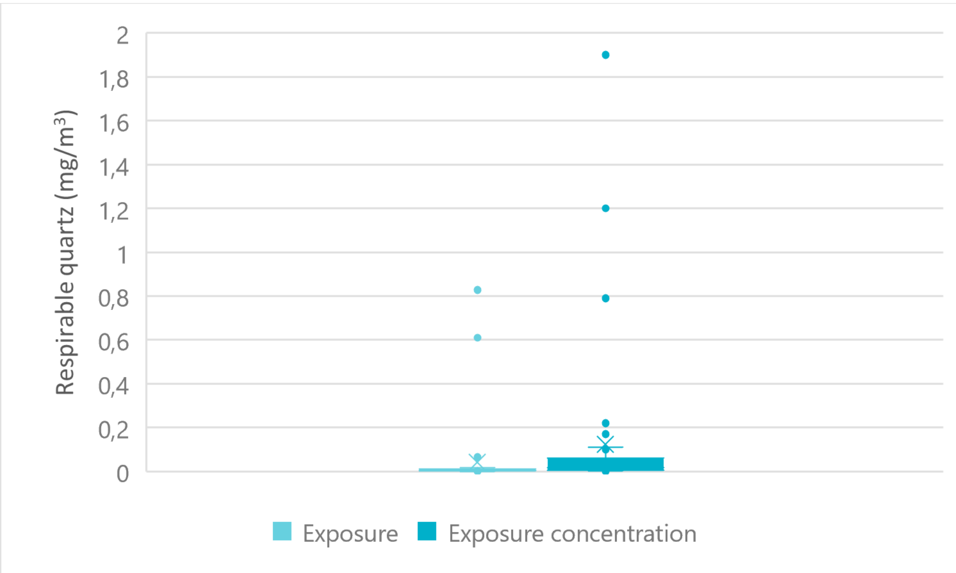

Figure 10. The effectiveness of respirator use in dusty work phases.

The distribution of quartz exposure by concentration category among workers who used respirators did not differ significantly from workers who did not use respirators (Fig. 11-12). The proportion of those who exceeded the ASA notification threshold, as well as the proportion of those who exceeded the OEL value or the binding statutory limit value, was surprisingly even higher among workers who used respirators (Table 5). Even while considering that these tasks often produced more quartz dust than tasks where respirators were not used, this is largely explained by the fact that, based on our observations, respirators were mostly used only when actively doing dusty work. As a result, outside the dusty work phases, particularly in indoor work, workers were exposed through the general air, because in indoor work in rooms with poor ventilation, the dust concentration of the general air decreases fairly slowly after the dusty work is stopped (Fig. 6, Tables 3-4).

Since the exposure concentration during dusty work phases was measured from workers regardless of whether they used a respirator, the effectiveness of respirator use to control exposure could also be examined on the basis of what the exposure would have been for workers who did not use a respirator, if they had protected themselves during dusty work phases. Since the use of respirators in that case would also have been limited only to dusty work phases and does not exclude exposure through general air outside of dusty activities, we end up with a smaller than desired decrease in exposure, i.e. 32% (median 10%, Fig. 13). If we remove from this group the tasks where the exposure was so low that the use of a respirator was not necessary, the exposure would have decreased by 63% (median 60%) by using respirators in dusty work phases.

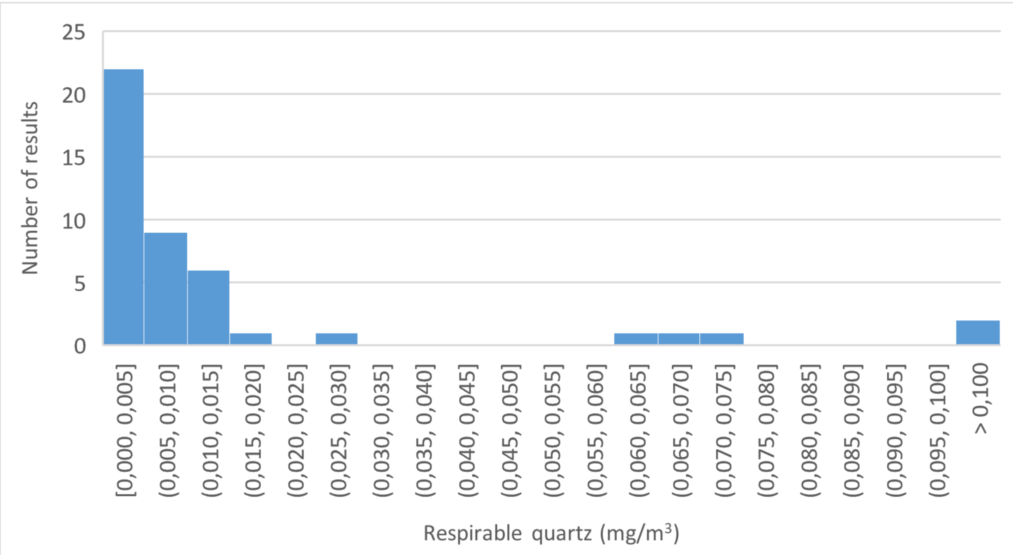

Figure 11. Distribution of respirable quartz exposure for workers wearing respirators.

Table 5. Respirable quartz exposure of workers in relation to respirator use.

	Respirator used	No respirator
Nr. of workers	44	106
Mean	0,043	0,022
Median	1,0	1,0
95 % percentile	0,073	0,069
Above 10 % of OEL	50	35
Significantly exposed (%>0,02 mg/m^3)	14	17
Exceeding OEL (%)	11	10
Exceeding statutory exposure limit (%)	5	4

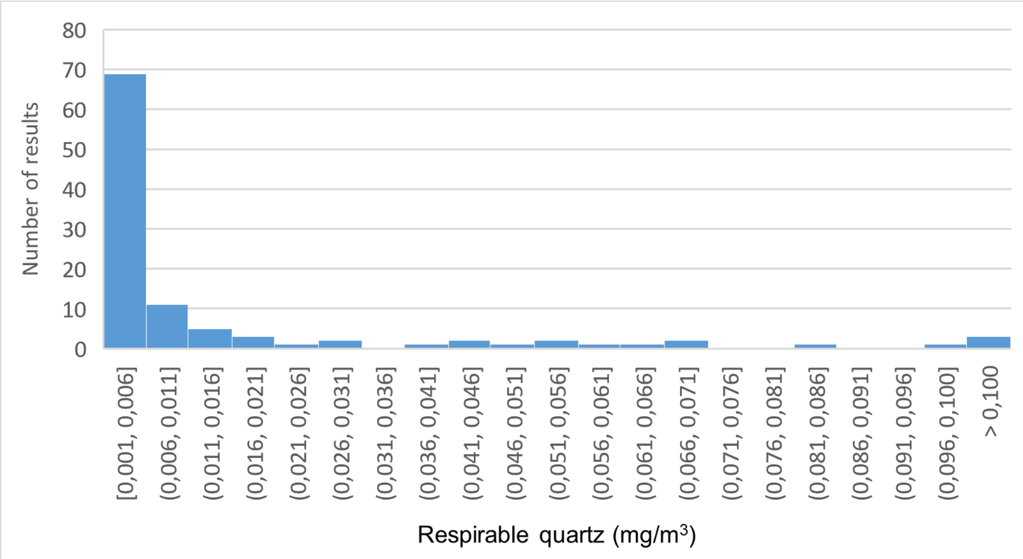

Figure 12. Distribution of respirable quartz exposure for workers not wearing respirators.

The conclusion is, once again, that when using a respirator for indoor work, exposure through the general air, and therefore also other dust-producing work performed in the department or on the floor, must be taken into account. If there is no ventilation in the premises, it can be assumed that a respirator must be worn throughout the working day in particularly dusty jobs, such as demolition hammering, drilling of hollow-core slabs, grinding of concrete floors, and levelling of partition walls and ceilings (Table 8, Appx. 1). Correspondingly, if, for example, demolition hammering or diamond sawing is done in an underpressurized area, the respirator can be removed while staying there no earlier than one hour after the cutting or sawing has ended, assuming that the air exchange rate is at least 6 h-1 [38], and no other dusty work is carried out in the section (see Table 8, Appx. 1).

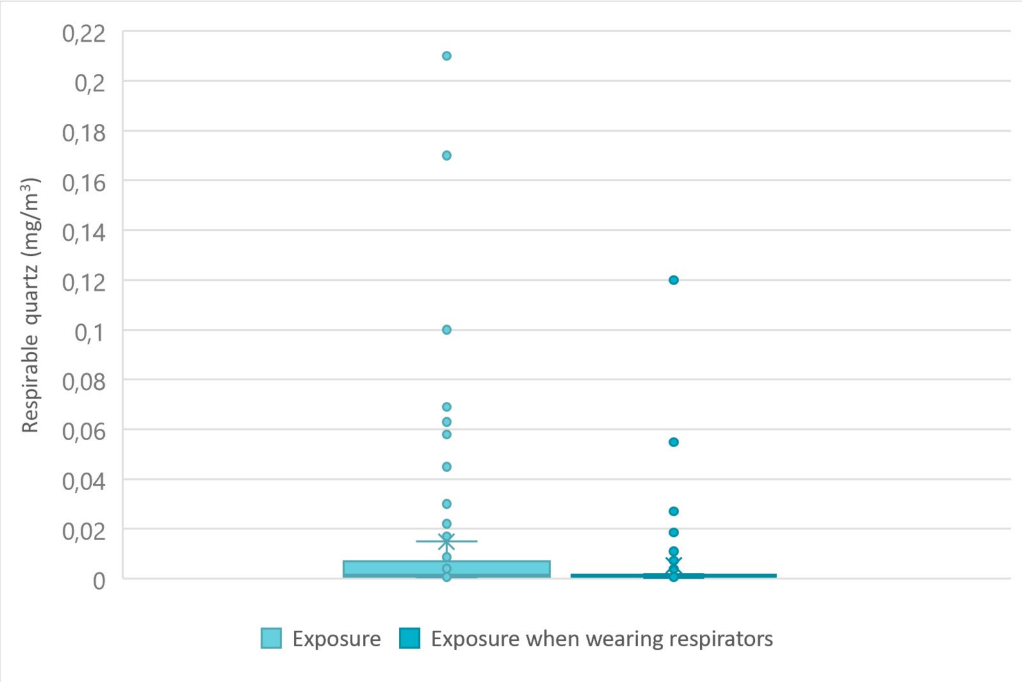

Figure 13. The potential of respirator use during dusty work phases to lower respirable quartz exposure of those workers who did not, in practice, wear respirators.

3.4 Respirable quartz and dust in the general air of construction sites

The general air concentrations measured on the construction sites were higher than the workers' exposures, both when comparing average exposures and 95 percentiles, as well as percentages exceeding the OEL and the statutory exposure limit (Tables 2-3). So as has already been repeatedly stated above, in many construction tasks, the contribution of quartz in the general air to the workers' exposure was very significant and should be taken into account, when assessing the need to use a respirator and the extent of its use outside of actively performing dusty activities. Only in most outdoor work can respirators be used only in tasks that produce dust or when working near sources of dust, because there the outside air washes away the dust formed quite quickly, the exception being hooded façade construction sites (Table 8, Appx. 1).

Overall, in this project, respirable quartz concentrations in the general air were of a fairly similar level to what has been previously reported by of e.g. Antonsson and Sahlberg [40], while the corresponding respirable dust concentrations were somewhat higher (Figure 14). Low general air respirable quartz concentrations (<0,005 mg/m^3) were mostly measured during outdoor work and in all the break rooms or containers we examined. Although high general air concentrations were also measured outdoors, e.g. at blasting sites and near the crusher at gravel pits and when pulverizing demolition concrete. The general air concentrations were also low in element installations (frame building) and interior construction cleaning, provided the work was properly executed and timed in relation to dust emitting work phases.

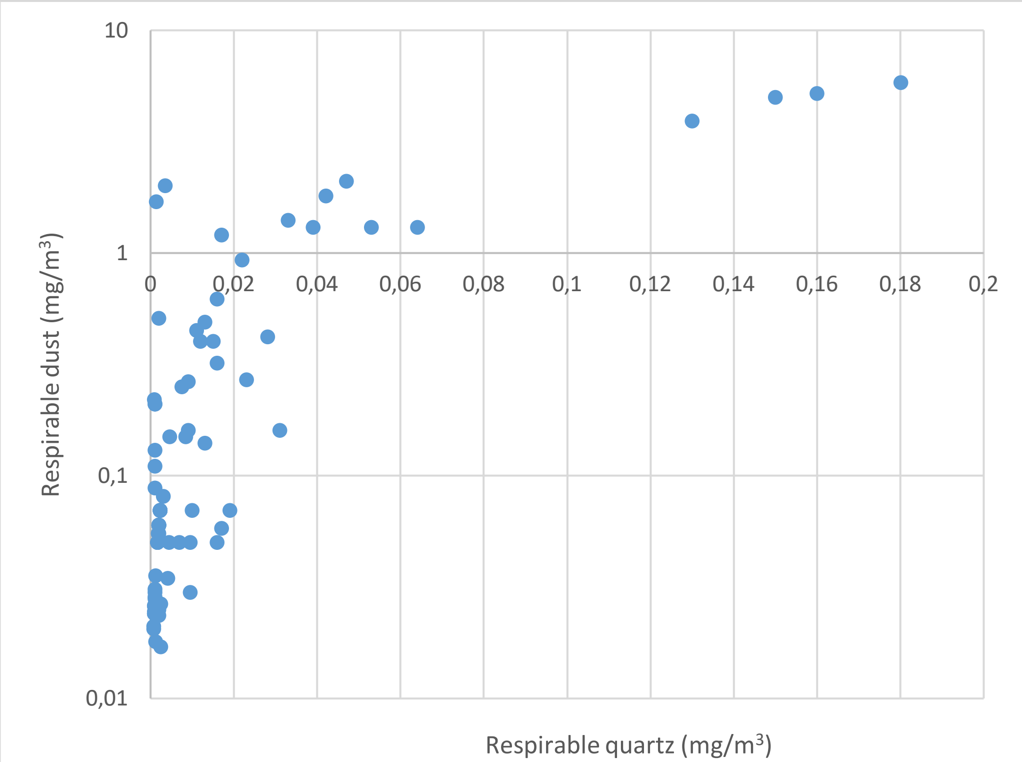

Figure 14. General air respirable quartz and dust concentrations at the investigated building sites.

3.5 Managing exposure with mobile air cleaners

Based on our measurements, mobile air cleaners can be successfully used to substantially reduce respirable quartz dust in the general air, e.g. in floor grinding, demolition hammering and levelling of indoor ceilings and walls. Provided they are placed close (1-2 meters) to dust-producing work and if the total air flow is sufficient in relation to the dust production in the space (Fig. 15; Table 8, Appx. 1). If the cleaner was placed at a distance of 1-2 meters from the dust source in an approx. 70 m^3 apartment, the general air concentrations were reduced with one 2 000 m^3/h air cleaner from a level corresponding to the OEL values to approx. one-fifth of the starting value. As a result, respirable quartz exposure through the general air decreased from excessive to low (Fig. 15).

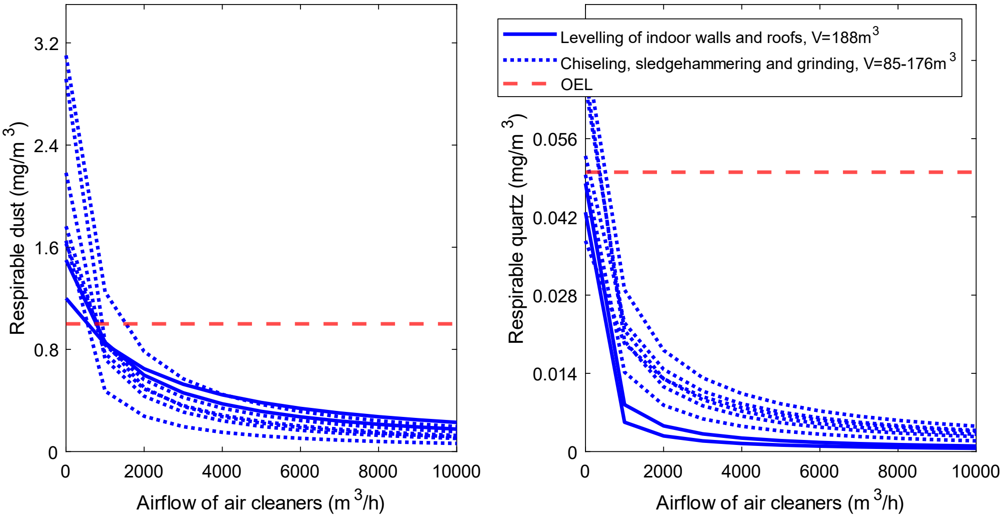

Figure 15. The air flow required for mobile air cleaners to effectively reduce respirable quartz and dust content in the general air in indoor work tasks.

3.6 Managing exposure in drilling rig operations

The highest exposures we measured outdoors were related to drilling with drilling rigs and working near them. The exposure of the drillers repeatedly exceeded the respirable quartz statutory limit value, when drills were void of cabins, and water was not used to control dust emissions. Regardless of whether the fine drilling waste (drilling mud) produced by the rear dust separator was bagged or not (Fig. 5, Table 4). Exposure exceeding the limit value was also measured in similar situations from primers who worked downwind, less than 10 m from drilling rigs (Fig. 5, Table 4). For this reason, we decided to test the effectiveness of three different options in the dust control of drilling rigs, namely dry drilling with the dust separators socked, water drilling, and water drilling combined with socks on dust separators (Fig. 3).

The highest concentrations in the test were measured during dry drilling, even though use of socks on dust separators kept the concentrations below the OEL even downwind, in the immediate vicinity of the rig. By using water and sock on the separators, all measured concentrations both in front of the rig, near the borehole, and behind it, downwind next to the rear dust separator, were low, i.e. less than 10% of the OEL (Fig 16). Consequently, during dry drilling with standard dust separators void of socks, the drilling rig operator should use a respirator at all times, if the rig is without a cabin and when working outside of the cabin. Applying socks on dust separators and using water can render respirators unnecessary during standard hole drilling, but probably not when focusing the drill during drilling of crevasses in bedrock. The latter setup was not tested, but on the construction sites investigated, crevasse drilling and particularly focusing the drill during crevasse drilling were the most problematic phases, due to dust emitted from the crevasse beside the borehole and, especially, because the dust exhaust vent surrounding the drill blade did not withhold dust emissions effectively when focusing the drill, until the drill penetrated the bedrock.

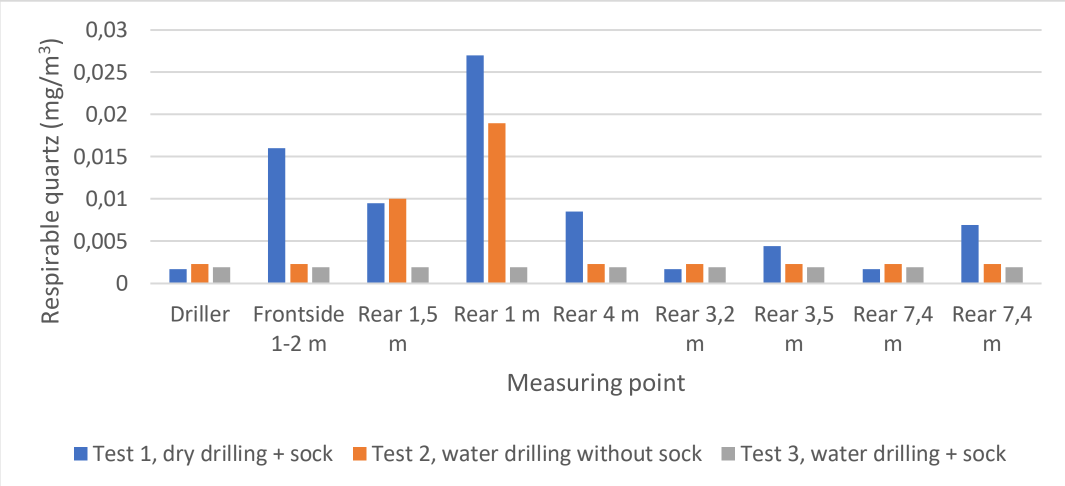

Figure 16. Respirable quartz exposure of the drill rig operator, operating a cabinless rig, and concentrations of respirable quartz downwind near the drilling rig, when using different dust control methods during drilling.

3.7 Managing exposure during the mixing of mortar

Using a mobile air cleaner with side walls (1300 m^3/h) in the mixing of mortar and placing the mixing vessel between the side walls (Fig. 1), effectively removed all measurable respirable dust from the mixing point air (Table 6). The concentration of respirable quartz in the mortar used was so low (< 0,2 %) that even without the air cleaner there was no measurable concentration of respirable quartz at the mixing point (Table 6). But since respirable dust released was practically completely removed, it can be assumed that the same is also true for respirable quartz when the product to be mixed has a higher concentration of it, e.g. in the order of one percent or more.

Table 6. Airborne respirable dust and quartz in the mixing of mortar, when using a mobile air cleaner equipped with airflow directing walls.

Exposure agent	No air cleaner	Air cleaner used
Respirable quartz (mg/m^3)	<0,0030[1]	<0,0040[1]
Respirable dust (mg/m^3)	1,7	<0,11[1]

[1]The concentration fell below the limit of quantitation.

In addition to a mobile air cleaner equipped with side-walls, a worktool-specific local exhaust vent connected to an H-class vacuum cleaner with a suction of 300 m^3/h was tested for controlling dust emissions in the mixing of mortars. This setup also effectively removed respirable dust as well as respirable quartz from the mixing point, the surrounding space, and the breathing zone of the employee mixing the mortar (Table 7).

Table 7. Airborne respirable dust and quartz in the mixing of mortar when using a worktool-specific local exhaust went connected to the blender.

	No exhaust vent		With exhaust vent	
Target of measurement	Quartz (mg/m^3)	Dust (mg/m^3)	Quartz (mg/m^3)	Dust (mg/m^3)
Breathing zone of worker	0,030	1,9	<0,0040[1]	<0,12[1]
Exposure of worker[2]	0,029	1,4	<0,0040[1]	<0,12[1]
Mortar mixing point	0,042	1,2	<0,0040[1]	<0,12[1]
Near the air exhaust vent of mixing room	0,078	3,0	<0,0040[1]	<0,12[1]
Near the air intake vent	0,068	2,6	<0,0040[1]	<0,12[1]

[1]Below the limit of quantitation.
[2]The worker mixing the mortar used a FFP3-class respirator only when actively mixing the mortar.

Consequently, both the mobile air cleaner and the worktool-specific local exhaust vent effectively removed dust and quartz in the mixing of mortar and, with the given airflows and equipments used, rendered respirators unnecessary. However, when mixing mortars without these methods to control dust emissions, at the least a FFP3-class respirator should be used when mixing mortar as well as when working indoors in poorly ventilated premises where mortar is mixed.

4 Conclusions

We assessed only construction work tasks that were seen as most challenging in terms of respirable quartz exposure. Consequently, e.g. in terms of average exposures, the results cannot be generalized to all construction tasks, but only to the part of the tasks that were studied. Among the workers monitored, the 60 % percentile of estimated exposures was less than 10 % of the OEL, i.e. low and below the ASA registering limit. In other words, most of the dust and exposure controlling measures applied on the construction sites were sufficient to keep the risks associated with quartz exposure acceptable.

On the other hand, the 90 % percentile of all estimated exposures was 0,05 mg/m^3, matching the OEL and the 95 % percentile was 0,2 mg/m^3, exceeding the statutory exposure limit by 100 %. This means that exposure was excessive in a significant portion of the work tasks studied. With most of the exposures being either due to not using respirators at all, or to not using them for long enough, after the dust emitting activity ceased. This does not mean, however, that respirators necessarily need to be used in all work tasks, where excessive exposures were recorded. In some of them, other dust or exposure controlling measures were shown to be sufficient. Namely, for instance, the use of water to control emissions as well as using work machines with appropriately ventilated cabins in many outdoor tasks. Further, outdoors, installing flexible socks to dust separators during water drilling with drill rigs were shown to be effective as well. Continuous use of respirators could be avoided in some of the indoor tasks associated with significant or excessive exposures as well. For ex. in tiling, using tile cutters instead of angle grinders and taking appropriate measures in the mixing of mortars, were shown to be sufficient measures to avoid excessive exposure, provided diamond drilling without respirators was not done. Also, using mobile air cleaners kept in the immediate vicinity of the dust emission source was an effective means to lower the respirable quartz content in the general air resulting from some of the dusty indoor work tasks.

Unfortunately, however, for the majority of the indoor tasks where excessive exposure was a concern, respirators need to be used not only when actively performing dust emitting activities, but during most of the working day, due to high general air quartz concentrations. That is, if mobile air cleaners or underpressure coupled with compartmentalization are not used to limit the spread and concentrations of emitted dust to the general air. More effective machine specific exhaust vents than those we encountered could make a difference. But as it stands, at least in the construction sites we investigated, from most of the work tools where either water or tool-specific local exhausts, or both, were used to control dust emissions, dust was still leaking and spreading to the general air in significant amounts. Either as such or, initially, contained in small dust containing water droplets. Albeit in smaller amounts than if such measures were not taken. And this necessitated the use of respirators while using them. In fact, in many work tasks, respirators were needed even after the dusty activity was ceased, while working in the same premises. As can be seen from the fact that the use of respirators, on average, lowered exposures only to half of what they would have been had they not been used at all. To give a typical example, if a worker actively grinds concrete floors for 60 % of a typical 8 h working day wearing a respirator with assisted ventilation. And for 30 % of the time stays in the same premises without the respirator, finishing corners, pipe inlets and radiator surroundings. And if the average quartz concentration in said premises corresponds to 0,072 mg/m^3, which was the average general air concentration in our study, his average exposure during said working day will amount to 0,022 mg/m^3 (43 % of OEL). This means that even though he wears a respirator during active grinding, the risk that he will contract silicosis may still be elevated, provided the day in question is a good representative of his career average exposure to respirable quartz.

All things considered, the take home message from our study is that all construction tasks, including those where excessive exposures were found, can be performed safely with the respirable quartz and dust exposures kept below 10 % of the OELs. Provided that appropriate dust and exposure controlling measures are followed, as listed in Table 8 (Appx. 1) and specified in the good practices published separately. And with that, there is no need for health checks. Provided that training programs are in place to give guidance in the procedures described, including the selection and use of respirators, and that their implementation is monitored effectively. On the other hand, in all tasks where the exposure was for the most part low, it was possible to be significantly exposed through the general air or by making bad choices in terms of dust control. As concerns respirable quartz exposure through the general air in such jobs, the timing of the work in relation to work tasks associated with high dust emissions is key, as is using the right type of respirators and the timing of their use, when necessary. The choice of respirators was generally correct on the construction sites we investigated. But instead, deficiencies were repeatedly found in their use and maintenance. As was also the case with the maintenance of vacuum cleaners, the planning, execution and oversight of compartmentalization and underpressurization, as well as in the implementation of common dust control measures, such as connecting local exhaust vents to devices or making sure that the vacuum cleaners connected to the exhaust vents were effective enough. In addition, work methods with low dust emissions were not always chosen when available. For instance, a contractor might have chosen not to use water in the demolition of buildings if, according to the contract, the contractor had to pay for the water. Even so, it is our opinion that when considering overall costs to employers, including the cost of insurance premiums, not to mention costs to the society and the public health care system, managing risks pertaining to respirable quartz exposure in the construction industry will in the long run be much more economical than the realization of those risks.

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APPENDIX 1

Work task specific exposures based on the exposure control measures used

Table 8. Estimates of exposure ranges in different work-tasks, based on the measurements performed. When exposure exceeds 10 % of OEL[1], ASA registering is obligatory, and when 40 % is surpassed[2], statutory health care monitoring is recommendable. The numbering pertaining to work tasks refer to the instruction cards (good-practices) published based on the present study (see Appx. 2): Kvartsialtistuminen ja sen hallinta rakentamisessa | Työterveyslaitos (ttl.fi).

1. Demolition of concrete buildings

Work task or workers	Execution and exposure control measures	Quartz exposure (mg/m³)	10 % of OEL[1]	40 % of OEL[2]
1.1 Demolition of buildings, shoveller or excavator copilot.	Water was not used to control dust emissions, or it was used too scantily. Respirators were not used.	0,05 - 0,005	x	x
	Water was not used for dust control. A FFP3-class respirator was used in dusty activities.	0,005 - 0,002	x	
	Structures to be demolished were dampened beforehand. Concrete waste as well as other dusty materials to be pulverized or moved were dampened prior to pulverization, transfer or sorting. No respirators were used.	<0,002		
1.2 Excavator pilot and other users of work machines equipped with cabins.	No water was used to control dust emissions. either the cabin windows were open, or the ventilation was closed or clogged up. No respirators in use.	0,025 - 0,005	x	x
	The cabin air intake was filtered (EN 15695-2). Respirators not used.	0,001 - 0,004		
1.3 Crusher (pulverizer) mill operator	Pulverization of dry or scantily dampened concrete waste. No respirator was used.	>0,05	x	x
	Pulverization of damp concrete waste. No respirator was used.	0,02 - 0,01	x	
	Pulverization of damp concrete waste. A FFP3-class respirator was used while working less than 5 meters from the crusher.	<0,002		

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2. Groundwork, green building, landscaping and infrastructure building

Work task	Execution and exposure control measures	Quartz exposure (mg/m³)	10 % of OEL[1]	40 % of OEL[2]
2.1 Shovellers, copilots, stonelayers and other workers working outside of cabins in earthmoving worksites.	Levelling of dry sand beds using plate compactors, cutting of stones with diamond saws, and seaming of stone pavings. Respirator was not used.	0,01 - 0,05	x	x
	Spreading of dry gravel brought with a front loader. Levelling of the dry bed with a plate compactor on a hot, still summer day. No respirator in use.	0,01 - 0,03	x	x
	Spreading of dampened gravel brought with a front loader. Levelling of the damp bed with a plate compactor. No respirator in use.	0,002 - 0,005		
	Watering and shovelling of soil and sand, in addition to traffic control. Respirator not used.	<0,005		
2.2 Primer of explosives and shoveller at excavation sites.	Worked in close proximation of and mostly downwind from drilling rig during the drilling of shot holes. No sock on dust separators. Water was not used.	>0,05	x	x
	Used respirator while working near drilling rig drilling shot holes. Water was not used.	0,005 - 0,02	x	
4.9 Cutting of slates and paving stones and other stone laying work.	Dry diamond sawing of stones and slates outside. Respirator was not worn.	0,02 - 0,1	x	x
	Dry diamond sawing, drilling and/or grinding of stone plates indoors using a machine-specific vent. No ventilation in premises. Respirator was worn only during the dusty activity.	>0,1 - 0,02	x	x
	Wet diamond sawing and drilling of stone plates indoors using a machine-specific vent. No ventilation in premises. Respirator was worn during the dusty activity.	0,005 - 0,02	x	
	Wet diamond sawing and drilling of stone plates indoors using a machine-specific vent. No ventilation in premises, but a mobile air cleaner was placed near the dust	<0,005		

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	emission source (2000 m³/h). Respirator was worn while working indoors.			
2.3 Drilling rig operators and primers of explosives	Dry crevasse drilling using a cabinless drilling rig. Socks were not installed on dust separators. No respirator.	0,05 - >0,1	x	x
	Primers working close (<10 m) to a drilling rig during dry drilling. No socks were installed on dust separators. Respirators were not used.	0,01 - 0,07	x	x
	Wet drilling of shot holes with a cabinless drilling rig. Socks were not installed on dust separators.	0,02 - >0,1	x	x
	Drilling of shot holes using a drill rig with a cabin. Windows were closed at all times.	<0,001 - 0,005		
	Primers working close (<10 m) to a drilling rig during dry drilling. Socks were installed on dust separators. Respirators were not used.	0,005 - 0,02	x	
	Primers working close (<10 m) to a drilling rig during wet drilling. Socks almost reaching the ground were installed on dust separators.	<0,001 - 0,005		
2.4 Green building	Levelling of dry sand beds using plate compactors, cutting of stones with diamond saws, and seaming of stone pavings. Respirator was not used.	0,01 - 0,05	x	x
	Levelling of wet sand beds using plate compactors, cutting of concrete slates with a slate cutter, and seaming of stone pavings using a squeegee to spread sand. Respirator was not used.	0,002 - 0,02	x	
	Stone laying: groundworks and installation of concrete slabs, grass stones and turf stones. A stone cutter was used to cut slates and a plate compactor to even the supporting dry sandbed. Bagged seaming sand was spread with a shovel and squeegee, and the seam seames settled using a plate compactor. No respirator was used.	0,005 - 0,02	x	
	Applying dry seaming sand to paving slab joints, supporting and straightening	0,003 - 0,03	x	x

	concrete retaining walls, and mixing concrete. Concrete was mixed with a shovel on the ground or in a wheelbarrow by adding gravel, sand, cement and water. Dry seaming sand was added to slab joints using a shovel and squeegee. The joints were settled with a plate compactor. The wind conditions were still. No respirator was used.			
	Spreading dry gravel brought by a front loader with a shovel and a levelling rake. Levelling the dry gravel bed with a plate compactor on a hot and windstill summers day. A respirator was not used.	0,01 - 0,03	x	x
	Spreading dry gravel brought by a front loader with a shovel and a levelling rake. Wetting the gravel bed and levelling it with a plate compactor on a hot and windstill summers day. A respirator was not used.	0,002 - 0,005		
2.5 Road construction	Evening a dry gravel bed spread out with a front loader and levelling it with a with a plate compactor on a hot and windstill summers day. A respirator was not used.	0,01 - 0,03	x	x
	Spreading dry gravel brought by a front loader. Wetting the gravel bed and levelling it with a plate compactor on a hot and windstill summers day. A respirator was not used.	0,002 - 0,005		
	Levelling a dry gravel roadbed with a cabinless compactor on a hot and windstill summers day. A respirator was not used.	0,002 - 0,005		
	Operating a cabinless asphalt milling machine or an asphalt milling machine with a cabin but with the windows open.	0,005 - 0,015	x	
	Copilot to an asphalt milling machine without respiratory protection.	0,005 - 0,025	x	x
	Jackhammering of the concrete coating of an old bridge without using a respirator.	0,02 - 0,05	x	
	Wetting and shoveling soil and gravel, in addition to traffic control. No respirator was used.	<0,005		

	Pilots of excavators, front loaders, milling machines and compactors, working in ventilated cabins with air intake filtration (EN 15695-2).	<0,005		
2.6 Railroad ballast loading and spread. Railroad rail supporting.	Technical supervision and control during loading and spread of railroad ballast and/or railroad rail supporting, adjusting the track brush tool when needed. No respiratory protection or wetting of ballast.	0,0037 - 0,037		
	Technical supervision and control during loading and spread of railroad ballast and/or railroad rail supporting, adjusting the track brush tool when needed. A FFP3-class respirator was used during dusty activities.	<0,005		

3 Frame building

Work task	Execution and exposure control measures	Quartz exposure (mg/m³)	10 % of OEL[1]	40 % of OEL[2]
3.1 Frame building and element installation.	Drilling multiple holes for support bars and post-installed reinforcing bars to balcony elements, below the top floor. Occasional passthroughs for rebar bars were jackhammered as well with a handheld jackhammer. Machine-specific vents were not installed to the drill, and respiratory protection was not used. The jackhammer was equipped with an exhaust vent to collect dust emissions.	0,005 - 0,02	x	
	Auxilliary work tasks in element building, such as constructing and attaching concrete formwork for corrective castings. Attaching veneer plywood and wooden structures to concrete elements by use of bolt drills. Machine specific exhaust vents or respiratory protection was not used during drilling.	0,005 - 0,02	x	
	Mixing mortar with a concrete mixer outside, in addition to installing inside wall elements. A respirator was not used.	<0,001 - 0,005		
	Rebar placing on the upper floor during frame building. No respiratory protection.	<0,001 - 0,005		

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	Drilling holes for element support bars on the upper floor during frame building. The drill lacked an exhaust vent. Respiratory protection was not used.	<0,001 - 0,005		

4 Indoor work in novel- and renovation building of apartment buildings

Work task	Execution and exposure control measures	Quartz exposure (mg/m^3)	10 % of OEL[1]	40 % of OEL[2]
4.1 Management	No respiratory protection was worn indoors, not even in dusty locations. No ventilation in premises.	0,005 - 0,01	x	
	Respiratory protection was worn indoors, in dusty premises. The premises were not ventilated.	0,002 - 0,004		
4.2 Construction cleaning	Vacuuming with a vacuum cleaner equipped with a HEPA-class filter but with no dust bag. Collection of larger debris with a brush and dustpan. The vacuum cleaner container was emptied directly to a roll-off dumpster, when necessary. A respirator was not worn, and no general ventilation was present in the workspaces. Mobile air cleaners were not used nor were underpressure applied to dusty compartments.	>0,05	x	x
	Vacuuming with a H-class vacuum cleaner and collection of larger debris with a squeegee and dustpan. A respirator was not worn, and no general ventilation was present in the workspaces. Mobile air cleaners were not used nor were underpressure applied to dusty compartments.	0,002 - 0,005		
	Vacuuming with a H-class vacuum cleaner and collection of larger debris with a squeegee and dustpan. General ventilation, underpressure and mobile air cleaners were absent, but a respirator was worn when using the squeegee and while working in proximity to dusty departments.	<0,002		
4.3 Grinding concrete floors	The floor grinder was not attached to an exhaust vent. A respirator was not used.	>0,1	x	x

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	General ventilation, underpressure and mobile air cleaners were absent as well.			
	An exhaust went was attached to the floor grinder via a collar. A respirator with assisted breathing was used while using the grinder, but not during other tasks. There were no general ventilation. Underpressure was not applied and mobile air cleaners were not used either.	0,02 - 0,05	x	x
	An exhaust went was attached to the floor grinder. A respirator with assisted breathing was used while using the grinder, but not during other tasks. The premises were compartmentalized and underpressure was applied, or mobile air cleaners with a similar air exchange ratio were placed close to the grinder.	0,002 - 0,02		x
	An exhaust went was attached to the floor grinder. A respirator with assisted breathing was used while working in the premises. The workspaces were compartmentalized and underpressure was applied, or mobile air cleaners with a similar air exchange ratio were placed close to the grinder.	<0,002		
4.4 Drilling (drying) of hollow-core slabs indoors	The drill was not connected to an exhaust vent and respirator was not worn. Premises were not ventilated. Underpressure was not applied and workspace-specific mobile air cleaners were not present.	>0,1 - 0,05	x	x
	The drill was equipped with an exhaust vent connected to a H-class vacuum cleaner (300 m^3/h). A respirator with assisted breathing was used while drilling. Underpressure was not applied and workspace-specific mobile air cleaners were not present.	0,01 - 0,05	x	x
	The drill was equipped with an exhaust vent connected to a H-class vacuum cleaner. A respirator with assisted breathing was used while drilling and when working in the workspaces where the drill had been used.	<0,002		

4.5 Drilling into concrete-, stone- or tile surfaces indoors	No ventilation in premises. A machine-specific exhaust vent was used while: - Continuously impulse drilling and using a respirator only while drilling. - Performing dry diamond drilling and using a respirator only when drilling.	0,01 - 0,05	x	x
	No ventilation in premises. A machine-specific exhaust vent was used while: - Performing wet diamond drilling without the use of a respirator. - Drilling a few singular holes of 20 mm diameter without a respirator.	0,005 - 0,01	x	
	No ventilation in premises. A machine-specific exhaust vent was used while: - Drilling singular holes with a diameter of 20 mm and using a respirator when drilling. - Continuously impulse drilling holes, and wearing a respirator while working in the same space. - Performing dry diamond drilling and using a respirator with assisted breathing at all times in the same space.	alle 0,005		
4.6 The mixing of mortars indoors	No respiratory protection were worn and there were no ventilation in premises. Underpressure was not applied, and mobile air cleaners were not used, nor were a work tool specific exhaust vent used to capture emitted dust.	0,005 - 0,02	x	
	A mobile air cleaner equipped with air flow (ca. 1000 m^3/h) directing side screens and, at the minimum, a M-class filter was installed at the mixing point.	<0,002		
4.7 Masonry work	No dust control while mixing mortar without the use of a respirator. Concrete bricks were cut with an angle grinder lacking an exhaust vent.	0,005 - 0,02	x	
	A mobile air cleaner equipped with air flow directing side screens was used to control dust emissions at the mixing point. Bricks were cut using a brick hammer.	<0,002		

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4.8 Levelling of indoor walls and roofs.	A work tool specific exhaust vent was connected to the sanding spatula used while grinding (sanding) rough patches on walls prior to applying sprayed mortar to walls. No respiratory protection was used and there were no ventilation in premises. Underpressure was not applied, and mobile air cleaners were not used to control dust emissions.	0,025 - 0,05	x	x
	A work tool specific exhaust vent was connected to the sanding spatula used while grinding (sanding) rough patches on walls prior to applying sprayed mortar to walls. No respirator was used, but underpressure was applied to the department, or a mobile air cleaner with a flow of 1 800 m³/h was in the vicinity while applying sprayed mortar, or when sanding walls with a tall sanding spatula connected to an exhaust vent (300 m³/h).	alle 0,002-0,005		
	A respirator with assisted breathing was used while working in the premises. Underpressure was applied to the department, or a mobile air cleaner with a flow of 1 800 m³/h was in the vicinity while applying sprayed mortar, or when sanding walls, using a tall sanding spatula connected to an exhaust vent (300 m³/h).	alle 0,002		
4.9 Cutting tiles and stone surfaces	Repeated dry cutting of stone slabs or retainers with diamond saws outdoors. No respirators in use.	0,02 - 0,1	x	x
	Dry cutting, drilling or grinding of stone surfaces indoors with equipment connected to an exhaust vent. No ventilation was present in premises and respirators were not worn outside of the dusty activity.	<0,1 - 0,02	x	x
	Wet cutting of stone surfaces indoors. A respirator with assisted breathing was used while cutting. The workspace had no general ventilation.	0,005 - 0,02	x	
	Wet cutting or wet drilling of stone surfaces indoors. A respirator with assisted breathing	<0,005		

	was used while cutting. The workspace had no general ventilation, but a mobile air cleaner with a flow of ca. 2000 m³/h was placed near the dust emission source.			
4.10 Making conduits for pipes or electrical wirings to walls and floors by grooving or jackhammering.	The workspaces were without ventilation. A machine-specific exhaust vent connected to a H-class vacuum cleaner was used. Respiratory protection was absent.	0,05 - 0,1	x	x
	The workspaces were without ventilation. A machine-specific exhaust vent connected to a H-class vacuum cleaner was used. A respirator with assisted breathing was used during jackhammering or when using the grooving machine.	0,005 - 0,02	x	
	The workspaces were not ventilated. A machine-specific exhaust vent connected to a H-class vacuum cleaner was used. A respirator with assisted breathing was used when working in the same premises, where jackhammering or grooving took place.	<0,005		
4.11 Grinding, levelling and patching.	Grinding of bathroom floors and walls with an angle grinder equipped with a diamond grinding wheel. Removing rough patches from corners between walls and floors with a jackhammer blade. The grinder had an exhaust vent, while a H-class vacuum cleaner inlet was held close to the jackham-mer chisel blade. In addition, mortar used in the evening of walls was mixed without the use of any local dust control measures. A P3-class respirator with assisted breathing was used during dusty activities, but not outside of them. Underpressure was achieved in the workspaces with a mobile air cleaner (1500 m³/min).	0,02 - 0,04	x	x
	Removal of paint and filler from concrete kitchen walls behind kitchen worktops by using an angle grinder and a dremer. The space was not ventilated. A disposable P2-class respirator was used during dusty activities but not outside of them.	0,003 - 0,02	x	

	Evening of concrete surfaces with an angle grinder, equipped with a diamond grinding wheel in addition to sporadic jackhammering with a handheld hammer. Both tools were without exhaust vents. A FFP3-class respirator was used during grinding and jackhammering. Also, gypsum mortar was mixed and spread out without dust control measures. The workspaces were not ventilated.	0,005 - 0,02	x	
	Gypsum mortar was mixed and used to fill patches in walls and roofs. There were no dustcontrol measures and a respirator was not used. The workspaces were not ventilated.	0,006 - 0,02	x	
	Finishing of walls and roofs prior to levelling them with mortar. An angle grinder was used to even rough patches and corners were evened with a small jackhammer equipped with a flat chisel blade. The grinder had an exhaust vent, while the jackhammer was without one. The premises were not ventilated. A P3-class respirator with assisted breathing was used during all times in the same workspace.	<0,005		
4.12 Tile laying	The mortar mixing point were without dust control measures. The tiles were cut and molded with an angle grinder lacking an exhaust vent. A respirator was not used and there were no ventilation present.	0,070 - 0,11	x	x
	The mortar mixing point were without dust control measures. The tiles were cut, for the most part, with a tile cutter and molded with an angle grinder lacking an exhaust vent. Inlets for wiring or water pipes were drilled with a diamond drill lacking an exhaust vent. A respirator was not used and there were no ventilation present.	0,01 - 0,04	x	x
	An air cleaner with airflow directing side screens was used while mixing the mortar. Tiles were, for the most part, cut with a tile cutter and molded using an angle grinder having an exhaust vent. Inlets for wiring or	<0,005		

	water pipes were drilled with a diamond drill lacking an exhaust vent. A FFP3-class respirator was used during cutting and drilling. There were no ventilation in the premises.			
4.13 Diamond drilling indoors	Dry drilling with a diamond drill equipped with an exhaust vent connected to a H-class vacuum cleaner (ca 300 m³/h). A respirator with assisted breathing was used only while drilling. The workspace was not ventilated.	0,01 - 0,05	x	x
	Wet drilling with a diamond drill lacking an exhaust vent, but the water and sludge were vacuumed during drilling by using a H-class vacuum cleaner with the hose kept close to the drill blade. A respirator was not used. Ten mm. holes for anchoring the diamond drill were dry drilled with an impact drill lacking an exhaust vent. The workspace was not ventilated.	0,03 - 0,06	x	x
	Wet drilling with a diamond drill connected to an exhaust vent. A respirator was not used and the workspace was not ventilated.	0,005 - 0,01	x	
	Wet or dry drilling with a diamond drill connected to an exhaust vent. A respirator with assisted breathing was used at all time while working in the same workspace.	<0,005		

5 Demolition of indoor structures in renovation building

Work task	Execution and exposure control measures	Quartz exposure (mg/m³)	10 % of OEL[1]	40 % of OEL[2]
5.1 Jackhammering of indoor walls and roofs.	No general ventilation in premises. Underpressure was not applied and respirators were not used.	>0,1	x	x
	A respirator with assisted breathing was used during jackhammering with a hammering robot. The department was isolated and underpressure was applied, the ventilation rate being ca. 10 h^{-1}.	>0,05	x	x
	A respirator with assisted breathing was used during jackhammering as well as while working in the same space. The department	alle 0,002		

APPENDIX 1

	was isolated and underpressure was applied, the ventilation rate being ca. 10 h^{-1}.			
5.2 Removal of fixed furnishings and surface materials.	Removing tiles with a jackhammer connected to an exhaust vent. Grinding of the underlying surface with a grinder equipped with an exhaust vent. A disposable FFP3 respirator was used during dusty activities. No underpressure were applied and the premises were not ventilated.	0,02 - 0,1	x	x
	Removal of kitchen furnishings and transferring them to dumpsters. No general ventilation was present, and respirators were not used.	alle 0,002		
	Removal of surface carpeting and cupboard materials and disposing of them to a dumpster. No general ventilation was present, and respirators were not used.	alle 0,002		
	Removal of glued plastic surface carpeting from concrete floors with a carpet removal machine. No general ventilation was present, and respirators were not used.	alle 0,002		

6 Façade work

Work task	Execution and exposure control measures	Quartz exposure (mg/m^3)	10 % of OEL[1]	40 % of OEL[2]
6.1 Sandblasting	The façade was enclosed with a plastic cover, a sandblasters helmet was used during sandblasting but not at other times. Water was led to the blasting sand with an integrated hose.	0,07 - 0,80	x	x
	The façade was enclosed with a plastic cover having occasional holes in it. A sandblasters helmet was used during sandblasting and while working inside the façade covering.	<0,0015		
6.2 Assisting tasks during sandblasting	The façade was enclosed with a plastic cover. The assistant did not spend much time inside the façade covering during active sandblasting. No respirator was used.	0,08 - 0,20	x	x
	The façade was enclosed with a plastic cover. A respirator was used when working	<0,0015		

	inside the façade covering even outside of active sandblasting.			
6.3 Renewing element seams	No façade covering was present. The old seaming was removed and the adhesion surfaces were cleaned using an angle grinder lacking an exhaust vent. The work progressed by proceeding downwards, one seam at a time, removing the seam and grinding the surfaces progressively at the same time. A respirator was not used.	0,05 - >0,1	x	x
	The façade was enclosed with a plastic cover. Removal of the old seam as well as cleaning of the surfaces were done progressively one floor at a time. A respirator with assisted breathing was used while doing this. Two workers were actively working on the same façade.	0,005 - 0,02	x	
	No façade covering was present. Removing the old seam was done separately from cleaning of the surfaces with an angle grinder lacking an exhaust vent. A respirator with assisted breathing was used during grinding.	0,005 - 0,01	x	
	No façade covering was present. Removing the old seam was done separately from cleaning of the surfaces with an angle grinder lacking an exhaust vent. A respirator with assisted breathing was used during both work phases.	alle 0,005		
6.4 Diamond sawing of façade elements	The façade was enclosed with a plastic cover. Elements were cut with a wet diamond saw to smaller blocks, to be transferred to a dumpster. A respirator was not used.	0,05 - >1	x	
	The façade was enclosed with a plastic cover. Elements were cut with a wet diamond saw to smaller blocks, to be transferred to a dumpster. A respirator with assisted breathing was worn at all times when working inside the façade covering.	<0,0015		
6.4 (2) Dry ice blasting	The façade was enclosed with a plastic cover. The surface underneath removed	0,005 - 0,020	x	

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	façade elements were cleaned from mineral wool isolation and other debris by dry ice blasting. A respirator with assisted breathing was worn during dry ice blasting.			

Good practices based on the present study published online:

Kvartsialtistuminen ja sen hallinta rakentamisessa | Työterveyslaitos (ttl.fi)

1. **Demolition of concrete buildings**
   1.1. Demolition of buildings, shoveller or excavator copilot
   1.2. Excavator pilot and other users of work machines equipped with cabins
   1.3. Crusher (pulverizer) mill operator
2. **Groundwork, green building, landscaping and infrastructure building**
   2.1. Shovellers, copilots, stonelayers and other workers working outside of cabins in earthmoving worksites
   2.2. Primer of explosives and shoveller at excavation sites
   2.3. Drilling rig operators and primers of explosives
   2.4. Green building
   2.5. Road construction
   2.6. Railroad ballast loading and spread. Railroad rail supporting
3. **Frame building**
   3.1. Frame building and element installation
4. **Indoor work in novel- and renovation building of apartment buildings**
   4.1. Management
   4.2. Construction cleaning
   4.3. Grinding concrete floors
   4.4. Drilling (drying) of hollow-core slabs indoors
   4.5. Drilling into concrete-, stone- or tile surfaces indoors
   4.6. The mixing of mortars indoors
   4.7. Masonry work
   4.8. Levelling of indoor walls and roofs
   4.9. Cutting tiles and stone surfaces
   4.10. Making conduits for pipes or electrical wirings to walls and floors by grooving or jackhammering
   4.11. Grinding, levelling and patching
   4.12. Tile layingLaatoitus
   4.13. Diamond drilling indoors
5. **Demolition of indoor structures in renovation building**
   5.1. Jackhammering of indoor walls and roofs
   5.2. Removal of fixed furnishings and surface materials
6. **Façade work**
   6.1. Sandblasting
   6.2. Assisting tasks during sandblasting
   6.3. Renewing element seams

This summary is the final report of the research project "Quartz Exposure and its Management in the Construction Industry" funded by the Finnish Work Environment Fund, the Confederation of Finnish Construction Industries RT, and the Finnish Construction Trade Union. The report outlines the safe performance of house building and infrastructure construction work that exposes you to respirable quartz dust. In essence, we describe how to perform dust producing worktasks with the exposure being less than 10 % of the current OEL (below the ASA registering threshold for those exposed to carcinogens at work). In addition, we list worktask specific solutions that lead to an exposure necessitating statutory health status monitoring by occupational health care (more than 40 % of OEL), and what methods are associated with excessive exposures (above OEL).

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