scientific reports

OPEN

Pollution of the environment and building interiors during asbestos removal as a result of lack of negative pressure in the working areas

Andrzej Obmiński

The paper presents examples of the consequences of the lack of negative pressure in the work zone during asbestos removal. The asbestos fibre concentrations generated in those work zones were relatively low. This was due to the leakage in barriers restricting the work zone. Therefore the asbestos content in the outside air, near the renovated rooms was increasing. In the cases discussed, these works resulted in short-term pollution of the building's outdoor air to a depth of up to 15 m. Such contamination can cover the entire interior of the building. This may lead to long-term retention of asbestos fibre in the facility, despite the completion of asbestos removal. For example, non-friable asbestos-cement sheets removal in those work conditions increased indoor air by contamination up to 3000 f/m^3 (outside the work zone). In the case of removing friable asbestos inside the building type "LIPSK", indoor air contamination locally was up 21,000–51,000 f/m^3, and outside the work zone to 18,000–28,900 f/m^3. These values are above the average concentration of asbestos fibres in the same type of buildings (< 300–400 f/m^3) in regular use.

Keywords Asbestos, Building materials, Indoor air, Outdoor air, Contamination, Airborne asbestos fibre, Asbestos removal

The problem study

During asbestos removal, the risk of asbestos fibre emission rapidly increases in the work zone. The exposure applies not only to contractors but also to users of buildings during and after the reclamation work, if airborne asbestos becomes uncontrollable. Generally, living near the source of asbestos increases the risk of exposure and then asbestos-related diseases[1]. It concerns not normal (passive) operation but is dependent on the state of product disturbance and in consequence transfer and increased levels of fibre concentration, especially during renovation or asbestos removal. Exposure to air contaminated with asbestos fibres results in asbestos-dependent diseases of the respiratory system (lung cancer, mesothelioma). Asbestos mineral fibres have a virtually unlimited "lifespan" and travel distance (downwind) in the environment and the building. Detection of asbestos fibre in outdoor air, particularly with periodic emission of asbestos (as in the asbestos removal work in the single building), can't be effective and the threat correctly assessed, because all processes last short. This contamination disperses rapidly in the environment. This is dependent on many internal and external factors. In outdoor air, only large and constant asbestos fibre emissions, such as in the manufacturing process, show a relatively good correlation between fibre concentration and distance from the emission source. Emissions associated with asbestos removal work or building demolition are periodic and lower than during the production process however, locally they significantly exceed the fibre concentration compared to the normal phase of building exploitation.

Permissibility of asbestos removal errors as a consequence of the lack of legally defined limits for asbestos fibers in the air

A limit of asbestos fibre concentration in indoor air during building use is very important in national legislation and the safe use of buildings contain asbestos materials. TLV, PEL, OEL (0.1 f/ccm) values cannot be used

Building Research Institute, Filtrowa 1, 00-611 Warsaw, Poland. email: a.obminski@itb.pl

as a criterion for acceptable levels of indoor air pollution for so-called continuous exposure. That sould applie workers, not refer to users and bystanders, being in that building for all time of their life without any protection, Typically, the concentration of asbestos fibres is drastically lowered after final cleaning, before the building is put back into use. However, in the event of important faults, polluted air levels in a room can exceed normal levels by more than 100 times and remain in the polluted room for long periods.

Although the level of fibers in indoor air may decrease over time, the overall increase in the concentration of fibers may in indoor air may be prolonged for up to several months (in some studies up to a dozen years)[2–4] because it is very high in the initial period during and after the removal of asbestos work is carried out. For example, samples collected during the removal of asbestos insulating boards (1.5–4.5 fibres/cm^3 and can extend shortlyn 30 f/cm[35]. These circumstances for building occupants and maintenance create a risk of greater exposure and the potential likelihood of asbestos related deseases risk. Some information on health risks caused by low asbestos exposure is presented in the last section.

In parallel with the lack of those limits for indoor air contamination in used buildings, many countries face the problem of inadequat contractors equipment, causing, for example, insufficient negative pressure in asbestos removal work zones. This resulted in a lack of control over the aerosol of asbestos dust generated in the air during the work. Destruction of products and the appearance of "free" fibres released from the matrix, is a relatively short-lived process. It is variable throughout the work process, depends on the phase of the work, and is difficult to estimate at the stage of the final assessment of the quality of the work, which is the final post-work air testing. In that case asbestos fibre aerosol "leaks" out of the sealed work zone what reduces the dust concentration in the workplace. At the same time, the "leakage" causes an increase in asbestos contamination of areas surrounding the work zone. The zones of the building contaminated by this process can often be outside the scope of the survey and assesing during acceptance attention of the work.

One question is what concentration of asbestos fibre may be caused by such workmanship errors?

Another question is what is a common foul and may appear in various circumstances and places. Therefore, the next question arises whether the action of general asbestos removal does not pose an increase in exposure to asbestos as an effect of wrong workmanship[6]. There are three types of measurements and samples to consider, which give different values for the concentration of asbestos fibres measured during a specific asbestos removal process: named: “personal samples”, if sampling was at a small distance from the breathing area of workers. The “area samples” if they are sample in a distance of more than “personal”, inside work areas. The third one is the “surrounding”, outside the confined work area (hermetically sealed working zone, where the ACM is dismantled).

Investigation theses and purpose

The article analysed selected cases of work in “area sampling” inside and outside the work zone, in indoor and outdoor buildings, where the elementary requirements of dust control were drastically not applied and a repeated execution error was the lack of tightness of the work zones and the lack of appropriate negative pressure in them. The results of these research are important because literature reports show the dependence of asbestos-related diseases such as respiratory cancers, on exposure and accumulation of exposure[7–9]. The author’s work aimed to determine the size and scope of the impact of these specific errors inside and outside buildings, to determine the migration rate of asbestos fibre and to analyse the concentration of their changes over time. This was best recorded for the buildings selected for this purpose and after developing appropriate methods for such analysis.

Method and materials

General assumptions of the methodology

As part of the study, several construction processes were selected, with the removal of products from the interior and exterior of buildings. A common feature was the lack of negative pressure in the work zone. Due to the lack of national criteria in the results assessment regulations, they were compared with literature data of similar works carried out in the West with appropriate care. The studies of the effects of the works described here concern works carried out between 2000 and 2019. The author’s results presented here (and his earlier research (Appendix A) are compared with those of the literature.

Air samples collected for the filters were analyzed for the concentration of asbestos repirabile fibres using a the author’s modified optical microscopy technique.

Air samples were taken by the author in different situations and places: used buildings without asbestos removal, during normal operation, and after asbestos removal, inside and outside the work area during the removal of friable and non-friable ACM. In all cases, there are significant, different technological errors in the removal of ACM. All described works were carried out by specialists in a careless manner and had in common the lack of a proper work zone. Mostly, these work zones were too large, leaky, or had periodic vacuum failures (at night, when work was not carried out). Sometimes work was carried out without separating the work zone and without negative pressure at all. They resembled the work of amateurs, not specialists, like DIY. A detailed demonstration of the working conditions for asbestos removal in the examples discussed is shown in the photographs in Appendices B1–B4: Figs. B1; B2: B3 and B4.

Description of the studied cases

Case 1. A large sports hall, external walls with ACM (asbestos-cement sheets)

The hall was a large sports facility. It is shown in Appendix B1 in Fig. B1.

The walls were in the form of a disc, inclined from the vertical. It contained two types of asbestos-cement products: PW3/A, sandwich panels with an area of 4,561 m^2 and a weight of approx. 51 tons and a façade, made of small tiles with an area of 3457.6 m^2, weight approx. 98.5 tons. The curtain wall of the hall was made of PW3/A sandwich panels. This board consisted of a thermal insulation core made of 4 cm thick polystyrene, clad on both sides with a 6 mm thick asbestos-cement board (non-friable asbestos product). The PW3/A boards were separated from the stands by a technical space. There were two types of ACM: curtain wall and facade panels. In the construction of the curtain wall, the PW3/A sandwich panels were screwed to the steel structure. It was possible to unscrew PW3/A boards from the technical rooms under the stands in a non-destructive way. The façade panels were attached to wooden battens, attached to the surface of the PW3/A panels. A section of the facade of this building is seen in the lower part of photo 4a. During the disassembly of construction products, "friable" products remained in the building (threads and seals of the ventilation system that were not to be removed).

Due to non-standard construction, the disassembly work was complicated. It was carried out without separation and encapsulation of the disassembly zones. In the work area, full containment and negative pressure were not performed. Locally, in the areas of disassembly of internal boards, the work zone was separated with PE foil. It was not an airtight zone with exit through the decontamination cabin. Therefore, as the staff moved, air pollution with asbestos fibers spread. It could migrate both inside and outside the facility. There was no central system for protecting the building against the emission of asbestos fibers, and as the works progressed and the defect (hole) in the external wall increased, the free exchange of internal and external air increased. The PW3/A boards were removed by "digging" them out of the mounting strips. Tests were conducted inside the building, in external zones, on scaffolding, and up to 80 m from the building.

Case 2. Disassembly of the facade of a high-rise building without vacuum in the work zone
Due to the narrow construction and renovation scaffolding, it was not possible to disassemble the a-c boards as sandwich board completely, without breaking (asbestos cement facade panels are non-friable asbestos products, containing 12% asbestos chrysotile. The very outside of the façade was covered with steel sheet panels. Under them, the outside of the asbestos cement panels was protected with protective paint, and the inside surfaces were unprotected). Between the a–c boards and the interior of the building, there were 2 layers of mineral wool, 10 cm boards each, PVC foil and plasterboards (the ACM did not come into contact with the indoor air either during use or during the removal of the ACM). Because the scaffolding platforms were too narrow and the ACM panels were too large to be dismantled as a whole, they were broken into smaller fragments on the whole surface of the building façade. That exigency and the removal asbestos methodology with technical means used are shown in Fig. B2: Appendix B2. The surface area of the asbestos cement panels (facade) was approximately 7000 m^2. All façade panels, due to their size, were broken during removal from the building wall. The contractors of the works did not use a hermetic cover made of PVC foil to separate the work zone, but only typical construction mesh to protect thicker fragments of boards that could fall outside the work zone. There was no central system for protecting the building against asbestos fibre emissions. The only protection inside the building was closed window openings, sealed from the outside with adhesive tape. This example is presented because of the lack of airtightness in the work zone and negative pressure during the removal of ACMs from facades. These are common practices. Measurements of air contamination were taken on the scaffolding and inside the building (before and during dismantling).

Case 3. Dismantling of asbestos-cement pipes inside a large facility, without building an airtight work zone
Asbestos-cement pipes were being dismantled inside a drinking water treatment plant in a large city. Sequences of connected pipe sections containing ~ 23% of asbestos, including 15% chrysotile and 8% crocidolite asbestos were removed after cutting them down to size. (It was impossible to remove them as intact pipes). Errors: no airtight sealing and no central system for protecting the building against asbestos fiber emissions. The pipes were cut into 1.5 m sections and cutting involved chopping 2/3 of the pipe diameter with an axe (Fig. B3 in Appendix B3). The remainder was broken with a hydraulic jack.

Case 4a Inadequate asbestos removal from walls and structures of a five-story "LIPSK" type building containing friable ACM (“SOKALIT” boards) and non-friable (a-c sandwich panels) inside
The structure of the building has been described in detail in previous articles[4,10]. The building contained 140 t of friable and non-friable products in walls and steel structure. The building featured modular panel exterior walls with and without windows. Each of them contained asbestos-cement boards called GLAGIT under the glass facade (non-friable product) and "soft" boards called SOKALIT on the inside (friable product). In addition to the building's external walls, friable boards were used in suspended ceilings and as covers for the building's structure, as well as fireproof covers for electrical cables above the ceiling. The weight of friable and non-friable products was approximately equal.

During work, the sealing system of the work zone did not meet the tightness requirements and maintained the negative pressure in the work zone at a level of 2 Pa (It should have reached 20 Pa) (Fig. B4 in Appendix B4), Between shifts, there was a loss of negative pressure in work zones due to "power outages". This was beyond the knowledge of the contractor and resulted in non-hermetic work zones.

During the dismantling of ACM, after each working day, when the closed building became empty (at night), the building security switched off the electricity to save energy. This shut down the vacuum-filtration units in the work areas, which should have been working continuously until the works were completed. The electricity was switched back on before work started. The workers were not aware of the repeated power cuts and vacuum drops. Asbestos fibres contaminated the entire building. The tests were performed inside the building to monitor the dismantling and to control the so-called "leakage" of contaminants outside the work zone.

Case 4b A building type "LIPSK" with one floor out of use, where interior asbestos walls were damaged. Asbestos fibre transmission from damaged "SOKALIT" boards on the 1st floor to the 5th floor which was normally used
No asbestos removal was carried out in the building. The measurements were performed approximately 7/8 months after the damage to the "SOPKALIT" boards (friable products).

Several sandwich panels named "SOKALIT" on the first floor of the building type "LIPSK" were significantly damaged. After determining the presence of asbestos in the damaged boards, all floors with rooms were closed and excluded from use. The same type of boards on the fifth floor were well-protected and had no damage. After a year, measurements of asbestos fibre concentration were carried out on the first floor and on the fifth floor, which were normally used.

Case 5 Rapid demolition of a small 1-storey building without the use of separate working zones with negative pressure
For comparison, the monitoring of pollution during the demolition of a small, single-storey building type MOA was monitored. It contained friable ACM (approx. 40 t of ACM) in the external and internal walls and ceilings. The building was quickly demolished without prior asbestos removal. An analysis of changes in internal and external pollution during the demolition of this building was carried out.

Sampling

The air samples were taken mostly inside and outside the work area and the others (background) were some distance from the studied buildings. Two techniques of air sampling were used:

- static, (natural, stagnant conditions, where the ambient air was not additionally mixed); That was for the samples when the ACM products were disassembled;
- dynamic, only in rooms, where asbestos was not being currently dismantled. For example, it was done after or before asbestos removal. The air was mixed using fans to activate settled asbestos fibres.

Sample analysis

Sample analyses were carried out using the PCM + PLM method (phase-contrast and polarized light microscopy), which has been previously, repeatedly verified by electron microscopy and comparative inter-laboratory studies. The samples were taken from inside the work zone, except the background samples, which were taken from a few meters away from the work in progress, or near the work zone (area samples). For this reason, the values of the area samples obtained here are not equivalent to the individual measurements of a sample from the breathing zone of workers. Their value is significantly lower. However, the information can provide a view of the scale of these threats. For microscopic analysis, the air samples were collected on filters made of Millipore AA cellulose esters with pore diameters of 0.8 µm. The flow volume of tested air was approx. 1.5 m^3. The time of sampling through each filter was ensured for two hours. The samples inside the work zone, except background samples, were taken from a few meters away from the work in progress, inside the work zone (area samples). Some of them as a leakage, were sampled at a different distance from the work zone. Building preparation conditions: the windows in buildings were closed during air sampling.

Analysis details

The author personally sampled, analyzed the circumstances of the work and carried out air tests at various stages of the work in terms of the concentration of asbestos respirable fibres (countable fibres according to WHO criteria, $L > 5$ µm, $Ø < 3$ µm and $L: Ø < 3: 1$). The sample analyses were carried out using the PCM + PLM method (phase-contrast and polarized light microscopy), which has been previously, repeatedly verified by electron microscopy (SEM–EDS and TEM) and comparative inter-laboratory studies.

The applied analysis method was described previously[11,12]. After chemically treating the filters, microscopic tests were performed, calculating the number of counted respirable fibres (PCM method), identified as asbestos fibres (PLM method). During microscopic analysis, the phase contrast technique according to the NIOSH 7400 method was used. The observation of each of the counted respirable fibres was supplemented with its identification using light polarization (based on optical features). The method of microscopic analysis using the OM technique was generally consistent with MDHS 39/41. The significant differences were the increase in the number of observation fields to about 400 and the use of magnifications up to 1000× with immersion. The number of observations of a single filter was about 4 times higher than with the NIOSH standard, which increased the sensitivity of the analyses. The adopted limit of quantification for this method is 300 f/m^3. The described method was a PCA-accredited research procedure developed in detail by the author and used at the Building Research Institute[13]. The expanded uncertainty of the results, determined in the computer program developed for the laboratory for these tests, amounts to approximately 20%. The selected microscopic research technique allows for a comparison of the historical results obtained by the author and other researchers, serving the assessment of threats. However, it does not pretend to be precisely marked as with the TEM technique[14,15] Although the TEM technique (US EPA 2021) is recommended for the identification of fibres in outdoor air, the author, as a mineralogist, decided to use the method of optical microscopy. This was due to the need to compare current results to the earlier ones, obtained with the same method, and also with the literature conclusion[14].

Indoor air		Before removal	Facade removal Period of the work Out of the work			Removal of walls containing PW3/A 0utof the work								
Days of work		0	1	15	29	34	36	42	54	59	72	96	110	f/m³
Place sampling	1	580–750	2100	3300	400	1100	2200	2400	1000	2400	580	860	380	
	2–3	< 300	1000	7100	300	1100	700	1300	900	1000	1200	460	390	
	4	1000	180–4300	300–3000	300–600	1000–1200	1350	1500–1600	Measurements have not been taken					

Table 1. Changes of indoor pollution ("area samples") over time, during asbestos removal in a single daily test. Place sampling of indoor air. 1. Balcony (above the stands, against the wall). 2. The middle of the sports hall. 3. Tribunes. 4. Technical space next to the wall.

			Before work	Facade removal		Removal of internal PW3/A panels							
Days of work			0	1–15	29	34	36	42	54	59	72	96	110
Distance from source Outside the building [m]	80	f/m³	< 300	900	800	300	400	500	700	< 300	400	300	-
	15		< 300	700–1000	1000–2000	Measurements have not been taken							

Table 2. Changes in outdoor "souranding" pollution. The concentration of asbestos and the distance from the object, during 110 days of monitoring in a single daily test.

Work stages		Number of measurements	Air pollution as asbestos fibre concentration, average/σ [f/m³]	
			Outdoor	Indoor
Before starting any preliminary work		21	< 300	< 300
Drilling the facade to attach the scaffolding to the building wall	Measurements on curtain and gable walls	21	980/250 870/90	880/60
10 days from the completion of the scaffolding		27	560/140 550/150	430/100 350/120
Removal of the external steel sheet cladding covering the asbestos-cement board to be dismantled	Measurements on curtain walls	24	350/40	< 300
Dismantling of a-c boards after removing the sheet metal façade, 4 months from the start works on scaffoldings. The technique is visible in the photos in Appenix B, Fig. B2	Measurements on curtain and gable walls	27	1150/660 860/270	1170/540

Table 3. Changes in the concentration of respirable asbestos fibres in the air during removal from asbestos-cement boards covered with an external cover of steel sheet panels in a 30-story building (during the following four months of work).

Test results

Case 1

The impacts of demolition on the external environment during the 100 days of asbestos removal are shown in Tables 1 and 2.

Case 2

During the removal of the elevation, indoor contamination inside the rooms with closed windows was averaged from 21 measurements < 300 f/m³, range 140–300 f/m³ σ = 100 f/m³;

Outdoor "area saples" (measurements taken on the scaffolding platforms, ~ 2.5–5 m from the demolition of asbestos plates) during the first month of work 800–3000 f/m³; σ = 700 f/m³; "Personal samples" were in the range 20,000–70,000 f/m³.

Detailed results of the air monitoring during work stages are presented in Table 3.

Case 3

The distance of air sampling from the pipe destruction was 4–15 m. Indoor contamination (inside the rooms) average 8000 f/m³ range 6000–20,000 f/m³; σ = 5000 f/m³; personal sample 20,000–80,000 f/m³.

Place of sampling		Registered leakage [f/m^3] during three workdays in place adjacent to the work area, which was treated as a "clean" area		Contamination of the building: "Leakage"—pollution outside the work zone, constituting [%] of the concentration inside the work zones			
		Wrong renovated "LIPSK" (uncontrolled power outages)				An example of a good standard of works	
		Range	Average/σ	After 3 days [%]	After 2 months [%]	After 3 days [%]	After 2 months [%]
V renovated floor		28,000–51,000	39,000/16,000	not measured		7	0.1
Leakage	IV non-renovated floor	14,000–23,500	18,700/6700	28	4–7		
	III non-renovated floor	13,600–28,900	21,250/10,800	27–60	9.2		
	II non-renovated floor	3200–7700	5500/3200	9.8–15.4	6.4		
	non-renovated ground floor	1800–5700	2500/2800	3.6–11.4	Not measured		

Table 4. Migration of asbestos fibres in a building contaminated by the incorrect of removal ACM (periodic negative pressure decay in the work area). Measurements outside the work zone, during works on the fifth floor. The data from this case was partially used in the author's previous article[12] to presentation "Changes in air pollution of three buildings type "LIPSK" within 48 weeks".

Floor in building	Contamination in the building before asbestos removal work			Contamination in the building during asbestos removal work (measurements outside the work zone, works on first floor)			Contamination in the building 7 days after asbestos removal work cleaning (in work zones)		
	Average [f/m^3]	Numb of sampling	σ [f/m^3]	Average [f/m^3]	Numb of sampling	σ [f/m^3]	Average [f/m^3]	Numb of sampling	σ [f/m^3]
V	700	5	141	2300	2	140	3800	2	1500
IV	260	8	200	2700	2	1000	12,170	2	15,300
III	260	6	220	4700	2	2100	13,000	1	Not measured
II	160	4	100	4000	2	2000	Not measured		
I	300	2	140	Not measured					
Staircase	300	2	150	21,000	2	10,900	Not measured		

Table 5. Migration of asbestos fibres in buildings when there was insufficient negative pressure in the work zone related to the removal of friable asbestos materials in the "LIPSK" building. Working vacuum 2 Pa instead of the required 20 Pa was caused by non-hermetic work zones.

Average asbestos fibre concentration on the I Flore with damaged ACM [f/m^3]	Average asbestos fibre concentration on the V Flore with clean rooms [f/m^3]	σ [f/m^3]
< 300	1360	730

Table 6. Asbestos fibre migration in the building between floors from damaged ACM to clean rooms (lack of control over the flow of air and asbestos fibre suspended in it).

Case 4a

Tables 4 and 5 show the numerical fibre concentrations in the 'clean zone' and the leakage as a result of work carried out in 'LIPSK' type buildings when the negative pressure in the work zone disappeared or was periodically insufficient.

Case 4b

See Table 6.

Case 5

Tables 7 and 8 show the impact of the demolished building-type "MOA" (with friable asbestos) on the surroundings over a short period.

Table 8 shows the changes in fibre concentration as the building demolition work progresses:

The disassembly of the roof caused the unsealing of the building and the mixing of pollutants inside with external pollutants. On the 19th day, the measurement "inside the demolished building" was carried out on the foundations, the remains of the demolished building, i.e. in the atmospheric air not limited by walls. For comparison, Tables 1-A1 and 1-A3 in Appendix A1 show some of the author's typical examples of asbestos fibre

Before asbestos removal						During and after asbestos removal				
Measured places	No. of sample	Average [f/m^3]	Max. [f/m^3]	Min [f/m^3]	σ [f/m^3]	No. of sample	Average [f/m^3]	Max. [f/m^3]	Min [f/m^3]	σ [f/m^3]
Removal building	2	< 300 (280)	312	< 300	50	5	2090	4800	1200	1990
Outdoor air	< 300					5	1020	2240	< 300	730
Adjacent school building (30 m)	2	< 300 (270)	< 300 (275)	< 300	10	3	< 300 (290)	440	< 300	170

Table 7. The demolished small building type "MOA" containing friable ACM and the neighbouring school building (in use, with closed windows).

Days of work	1	2	3	4	7	13	14	15	16	18	19	
Advancement of dismantling works	Before disassembly + preparation zones of work				Start	Walls	Roof	Final	Waste disposal			Place of measurement
Fibre concentrations [f/m^3]	< 300	< 300	< 300	< 300	< 300	400	600	2200	600	300	< 300	15 m from the works, 2 m outside the building
	300	300	300	300	1200	3600	4800	1200	600	700	600	Inside the demolished building MOA
	< 300	< 300	< 300	< 300	< 300	< 300	< 300	< 300	< 300	< 300	< 300	Inside the other building, 30 m away from the works

Table 8. Changes in environmental pollution as demolition work progresses.

concentrations mixed at different distances from the emission source, during different improper asbestos activities, and disturbance of asbestos products. ACM destruction activities and measurements were carried out in an open space without dust barriers[11,12].

Discussion

Analysis of changes in concentration of asbestos fibre in the cases in question

Case 1

Outdoor air pollution, generated during the disassembly of the ACM at a distance of 15–80 m from the pollution source, had values about 3–7 times lower than indoor air (Fig. 1a).

The maximum initial asbestos fibre concentration in outdoor air after removing the façade preceded the maximum concentration recorded inside the building. About eighteen days later, the situation was reversed. This was caused by the unsealing of the walls of the building (as in Case No. 5). Outdoor air pollution and the dynamics of its changes were inversely proportional to the distance from the building. The charts depicted in Fig. 1a,b provide a clear representation of the diverse functions explaining the changes in asbestos fibre levels detected at different distances from the structure.

Unlike the outdoor air, the indoor air was subject to large fluctuations during the asbestos removal. Although there was an inadequate separation between work zones and the rooms were quite large, the indoor air was characterised by significantly higher levels of changes and asbestos fibre concentration values. This was due to the higher concentration of asbestos fibres generated at the emission source and the lower degree of dispersion of the airborne asbestos fibre. The values recorded using an optical microscope are on average half of those recorded using an electron microscope[15]. Literature data[16] in equivalent situations show "personal sample" of 100,000–300,000 f/m^3. However, the maximum "area sample" contamination measured here, with similar works was only ≈7000 f/m^3. This means that the giant pollutant stream was dispersed in the internal and the external environment of the building. The residual volume outside at a distance of 15 m from the source was only ≈ 2000 f/m^3.

In Case 1, the graph of indoor air pollution changes is a polynomial function and is presented in Fig. 1b. It estimates the average concentration and contamination trend changes in this building during periods of renovation. Coloured points indicate the location of indoor samples at different distances from the dismantling walls.

Case 5

Figure 2 presents trends of changes in air contamination during improper demolition of a small building-type "MOA". The work caused a short-term increase in asbestos concentration in the outdoor air. At the maximum intensity of work (14th day of work), at a distance of 15 m from the work zone, there was a ≈ seven to eightfold increase in the concentration of asbestos in the air compared to the levels before disassembly. It took 4 days for the outside air to return to its original state before the asbestos removal work. Generally, the concentration of asbestos in the air inside the demolished building impacted outdoor air pollution. Despite being located 30 m away from the site, there were no significant variations in asbestos fibre levels detected inside the school building. After analyzing Figs. 1a,b and 2, it is evident that the concentration of asbestos in the air decreases significantly with an increase in distance from the emission source. The data also indicate a decreased dynamic of those variations in the levels of asbestos over time. Due to different physical processes, such as gravitational settling and air exchange in the building, asbestos fibre concentrations in all rooms and their surroundings decreased over time and varied depending on the prevailing conditions. The concentration of fibre and the shape of the trend of

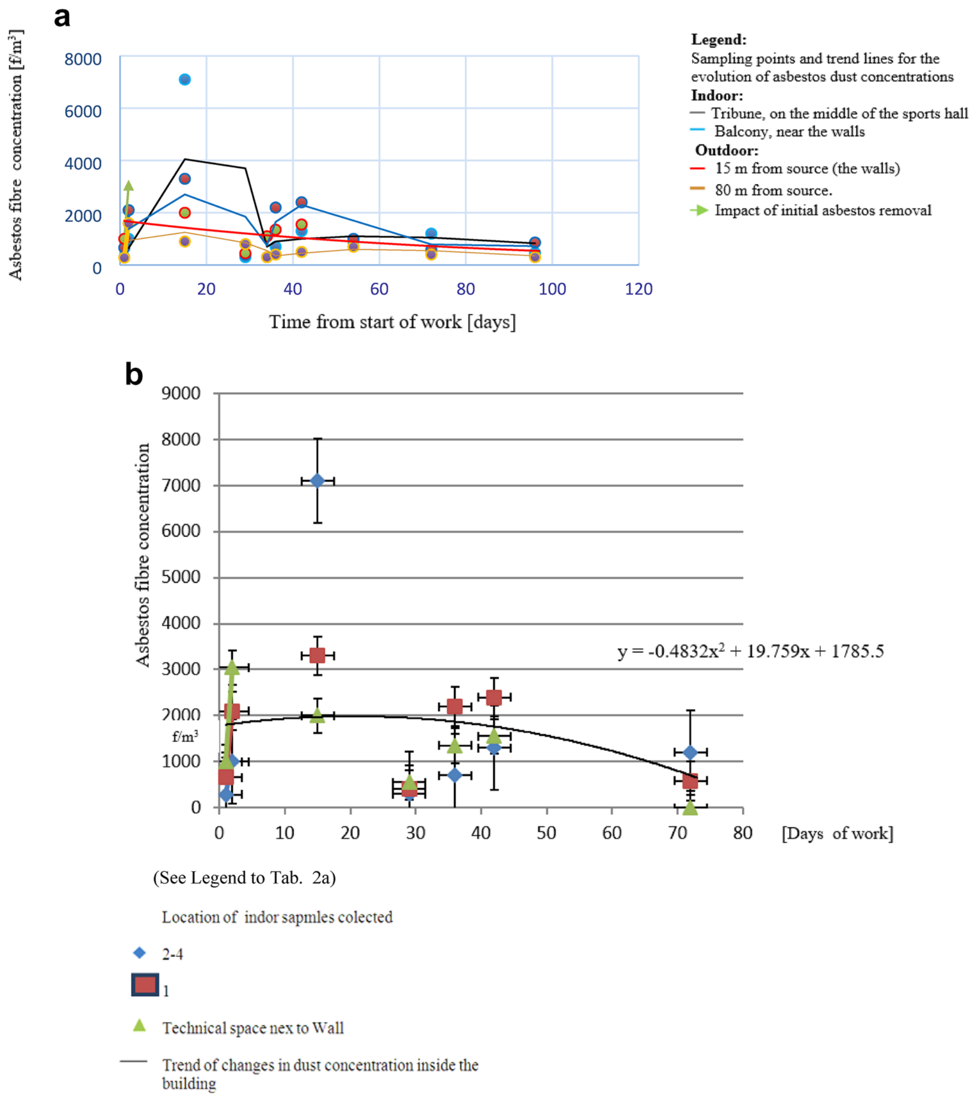

Fig. 1. (**a**) Changes of asbestos concentration [f/m³] in outdoor and indoor air over 100 days. The break-in work occurred between the 28th and the 32-nd day. (**b**) Duration of dismantling work. The analysis and general trend of indoor air changes during the progress of asbestos removal and the trend of changes in asbestos fibre concentration inside the building are based on averaging momentary values.

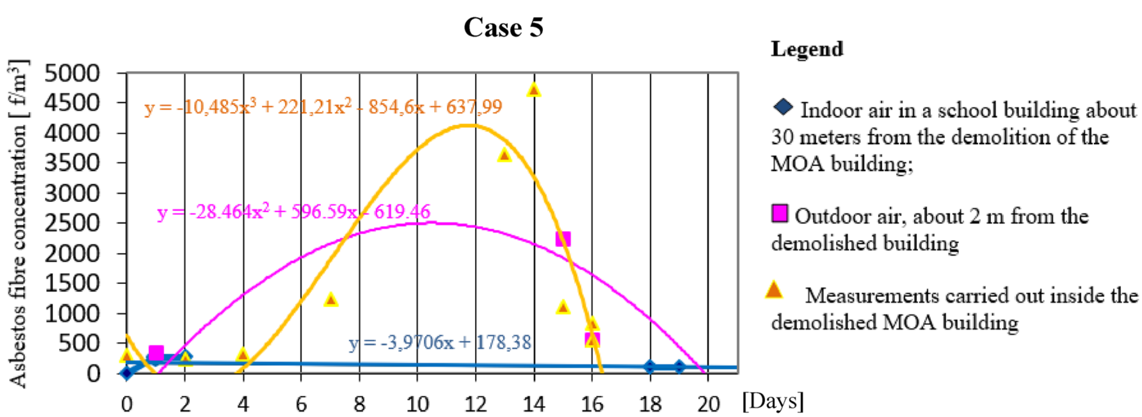

Fig. 2. The course of changes in the concentration of asbestos in the air during the demolition of a building containing ACM and trend lines of changes in pollution in various environments.

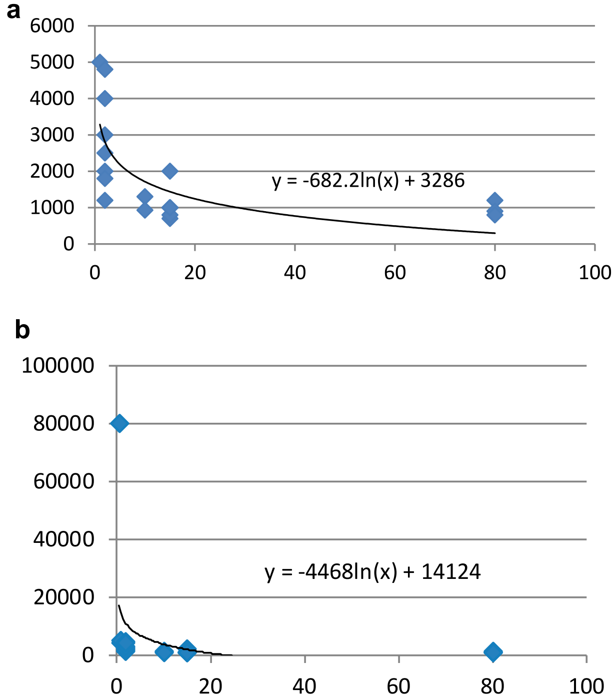

Fig. 3. (**a**) Dismantling the sandwich walls containing panels covered with the asbestos-cement board on both sides. The trend line of changes in pollution in outdoor air in the vicinity of large buildings with ACM removal as a function of distance from the asbestos fibre source (x-axis [m]; y-axis [f/m^3]). (**b**) Dismantling only façade panels containing asbestos-cement boards (x-axis [m]; y-axis [f/m^3]).

changes curve depended on: the scale and type of damage to the ACM panels, the time which had elapsed since the destruction of products, and the extent to which they were covered with paint. In the case of indoors, those changes initially depend on the ventilation of the rooms, the intensity of use, including vibration of the walls and floors, and the degree of air exchange. Although the values presented by the author in the general scope of building operation coincide with other reports[17] they are limited by the sensitivity of the technique used. From the presented relationships between various OM, SEM, and TEM methods,[15] it follows that the real exposure levels of workers, staff and building users, measured by electron microscopy would be 2 times higher than those measured by the OM technique (which can register fibres with diameters > 0.2 µm). As a general conclusion, in the described building situations, the risk of contamination of the building and its surroundings appears, but it can be hard to detect.

Air pollution values can be underestimated in and out of work zones due to leakage and mixing of indoor and outdoor air. The course of the indoor air pollution changes and trend line showing changes in the concentration of particulate matter over time (Figs. 1b, 2 and 3) are different in each of the cases discussed. This applies to the dynamics of change and the type of function that best approximates the trend line. The reason is the variety of conditions for forming and maintaining asbestos airborne fibre.

Taking into account the repeated exposure of workers, as well as the effects of improper work with asbestos in the neighbourhood, an increase in the risk of certain diseases as a result of asbestos exposure cannot be ruled out. Many sources are responsible for them, such as building environmental pollution and factors other than the momentary measured exposure[18–21].

Comparison of the value of asbestos airborne fibre with friable and non-friable products

- The highest fibre concentration was restricted when removing friable products in the working zones of a "LIPSK" type building (up to approx. 50,000 f/m^3).

- In similar work carried out in a smaller "MOA" building, the fibre concentration value was ≈ 10 times lower. This was the result of unsealing the interior of the building by removing the windows and the flat roof.
- During minor renovation works (painting the walls, without asbestos removal) of the interior of a "BERLIN" type building carried out without ACM protection using the required techniques, the level of asbestos fibres in the air was equal to the level during the destruction of ACM products in the "MOA" building. Buildings type "MOA" and "BERLIN" are similar in size, number and type of friable and non-friable ACM.
- During the destruction and movement of non-friable (asbestos-cement) products—cases 1 and 3, the concentration of asbestos fibres in the indoor air was at a similar level of 7000–8000 f/m^3. Personal sampls in measurements in case 3, showed concentrations in the range of 20,000–80,000 f/m^3. The destruction of non-friable products does not necessarily mean a low risk of released dust and depends on the characteristics of the environment, the possibility of dust dispersion in the environment, and the scale and type of work (see Appendix 1).

Discussion in general

The common characteristic fault in the discussed cases 1–5 is the general problem in the correct preparation of the work zone, and its air-tightness. The practice of work may differ from theoretical procedures often. All of the discussed works, had a lack of negative pressure in the work zone and a lack of air filtering units inside this zone, blowing the filtered air outside the facility. This condition led to the dispersion of fibre emissions outside the work area. In the work zone, and therefore in the worker's breathing zone, the supply of outside air was as free as in an open space outside the building and lowered the fibre concentration. At the same time, the concentration of these fibres increased in the surroundings, outside the work zone. This is a natural effect of the transport of all asbestos dust and fibres in the air.

The final effect is influenced by many factors, such as the ventilation characteristics of the building, the type of work carried out in it, the scale of damage and the consistency of the ACM matrix, the duration of work, and in the case of work outside the building, weather conditions[11,12].

In these circumstances, during the works, the fibre concentration in the indoor air was lower than should be (cases 1, 3 and 5). The values of fibre concentration measured during these activities are 10–100 times lower than expected. At the same time, outside the interior work zone (cases 1 and 5) the fibre concentration increases ≈10 x. After the inner work was completed, the indoor air contamination was generally greater than earlier, before the renovation. In the case of buildings such as BERLIN and LEIPSIK which contain 10 and 40 t of friable ACM in the walls, after faulty dismantling, this may be an increase of 10–20×[19]. If more mistakes were made in asbestos removal, e.g. by using the "wet method" to use water to wet the ACM instead of using specialized agents, contamination over time could still increase for several months, depending on the internal air exchange rate[2,3,11]. A large spread of the results of the fibre concentration characterized all cases in the described rooms. In the air surrounding the building at a distance of about 10–15 m, the increase in pollution from the leak (cases 1 and 5) was delayed by at least one day, and the maximum values of fibre concentration reached 2000–2200 f/m^3.

A good example of the changes in the concentration of asbestos fibers inside and outside a rehabilitated building in the absence of negative pressure in the work zone is shown in Tables 1, 2, 3, 4, 5, 6, 7, 8. The changes in concentration described are due to the rapid dispersion of asbestos dust, especially in the outdoor air. An example of the dispersion of asbestos fibre-borne concentration is the penetration of asbestos dust into the interior of buildings with closed windows (probably through doors, unswitched ventilation sytem or unsealing of windows by users in Case 2):

a. building with removed facade Case 2 (increase in the concentration of asbestos dust in the indoor air due to the proximity of the emission source)
b. the building 30 m away from the MOA-type building being demolished, case 5 (no increase in dust concentration). Some more examples and comparisons of the results and variations in measured values between work areas and their surroundings were presented in Appendix A1, Table 1-A–3-A. Results of measurements at various distances from the emission source are presented in Tab. 2-A. Table 9 summarises the cases discussed in German regulations. Regarding this regulation[22] the required fiber concentration limit after ACM removal is 500 [F/m^3].

Despite the complete lack of appropriate technique, in case 5, the asbestos fibre concentration limits for workers are not exceeded due to the unsealing of the building by removing windows and the roof.

The differences in exposure levels of people exposed in and out of the work zone at two "LIPSK"—type building during correct and incorrect renovation, are graphically shown in Fig. 1-C in Appendix C. This figure summarises the essence of the problem at hand. Figures 3 and 4 show trends in asbestos fibre concentration changes over time. The emerging UE legislation on the use of buildings with asbestos and on the risks involved in renovating them still does not adopt common limit values for indoor air contamination. The lack of adoption of such limits in many countries has remained unresolved for years[17]. This results in the exposure of occupants of operational and renovated buildings to unknown levels of concentrations of asbestos dust.

The trend line of changes in pollution in outdoor air in the vicinity of large buildings with ACM removal as a function of distance from the asbestos fibre source is graphically presented below in Fig. 3a and b. Pollution in "BERLIN"-type and "LIPSK"-type buildings with execution errors causing leakage from the work area are presented in Fig. 4. This is a consequence of the process illustrated in Fig. 1-C in Appendix C.

Some additional important information on outstanding legal issues[17] regarding air pollution limits for asbestos fibres is included in Appendix D and the bibliography[6,17,23].

Case	5	1	2 and 3	4a
The size of the building	Small, two-story	Wary big sports hall	Wary big buildings	Medium size, 5-story building
Type of work	Demolition	Asbestos removal	Asbestos removal	Asbestos removal
Type of ACM	Friable	Non-friable	Non- friable	Non-friable + friable
Conditions for air sampling (time from the completion of the works)	2–3 week	2 week	Measurements were not taken inside the buildings after the completion of the work	1 week
Aver. [F/m^3]	1200	≈ 400		3800–13,000 (on different stairs)
Reason	No dust control when removing ACM, a lack of appropriate disassembly technique, and separate work zone, no windows and no roof, and mixing of polluted indoor air with atmospheric air	No separate work zone, mixing of polluted indoor air with atmospheric air		The work zone is leaky, negative pressure 5 times in the work zone is too high, and periodically (at night) completely turned off with negative pressure before the works are completed and the work zone is cleaned
The effect, the limit exceeding	2.3× exceeded the limit	The limit was not exceeded, however, most of the asbestos asbestos fibre from this work was discharged into the building's surroundings		7.6–26× exceeded the limit

Table 9. Summary of the chosen results, regarding German regulation TRGS 519.

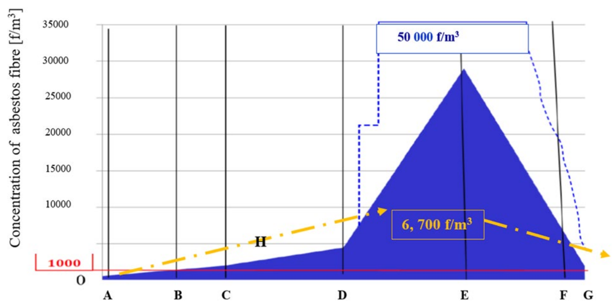

Fig. 4. Comparison of pollution in "LIPSK"-type buildings with execution errors causing leakage from the work area and results of minor renovation (renovation, plastering and painting of internal walls) with a lack of knowledge of employees about the presence of asbestos in renovated walls. (PCM measurement). A Building with intact ACM products (not renovated), in good technical condition; B Building a few years after standard renovation and adaptation work. C Rooms not renovated adjacent to asbestos dismantling carried out in a single room after several months; D Premises during the commencement of works, a few weeks after the commencement of asbestos dismantling—before the main asbestos removal phase; F Rooms after asbestos removal and final cleaning; E Rooms outside the hermetic work zone, during disassembly, of ACM and leakage; G Rooms after asbestos removal, about two/three years after completion of disassembly, cleaning and commissioning. H Premises of the BERLIN building (smaller version of the LIPSK building) undergoing small-scale renovation (renovation, plastering and painting of internal walls). Workers' lack of knowledge of the presence of asbestos in renovated walls. There was no central system for protecting the building against asbestos fiber emissions during the deterioration and destruction of friable asbestos products.

Comparison of literature data to the author's results

Comparison literature data on concentration fibre values to the author's investigation is presented in Table 10.

Some additional examples of the author's measured data (Appendix A) and other researchers' historical tests in relation to health impact were presented in other similar measurement zones[33–35].

Differences in asbestos fibre concentrations during operation and asbestos removal are presented in several examples in the literature data below and corresponding to the author's data in Table 10.

Of the historical measurements of occupational asbestos exposures in product production and construction work, 26% of the results exceeded 3,000,000 f/m^3. About 29% were in the range of 600,000–3000,000 f/m^3. About 44% of the results were in the range < 100,000–600,000 f/m^3. About 50% of the results of mean measurements of asbestos fibre concentration were in the range of 100,000–3,000,000 f/m^3 in the min–max range 40,000–7,000,000 f/m^3[23]. A number of studies in this area for various activities or demolitions were confirmed by numerous works and were described by the team's of authors Lange and Thomulka.

The values obtained from "area samples" are much lower than taken from the worker's breathing zone, named "personal samples"[16,30,36,37]

The author obtained the results during asbestos removal tests: "area samples" inside buildings on the level approx. 6000–40,000 f/m^3[11,28] and "personal sample"[2,3,12] values in the range 7000–50,000 f/m^3). In these long-term studies, the author's results were, in his opinion, much lower than they should have been, and much lower

The air measurement in buildings	Analysis Method	Asbestos concentration [f/m^3]	[References]
Exploitation phase of a building			
Schools, residential buildings, and offices (non-friable and friable asbestos products)	TEM	100–300 fibres 10,000 asbestos structures[1]	24
Heating systems, using a soft insulation board, simulating operational disturbances (friable)	TEM	< 50	25
General	TEM	40–2000, on average 200–500	26
Damaged ACM products (suspended ceiling) in buildings	TEM	< 8000, max. 7000–8000 s[1]	27
Normal operation, all construction: non-right, mostly steel and rigid, mostly brick and forced concrete (friable + non-friable)	The author's data: PCM + PLM	On average < 300–700, med 300	2,3,11
Normal operation in bad condition (friable)		On average 800–1400, med. 1100	2,11
Very bad condition (friable)		500–8000, med. 1700	11,28,29
Destruction process, asbestos removal			
ACM roofing removal, area samples outdoor (non-friable)	PCM	600–16,000;	30
Demolition of houses with asbestos-cement products (roofs, facades), personal samples Asbestos removal of all construction: non-right, mostly steel and rigid too	PCM/SEM	10,000–150,000 20,000–420,000	31
Estimated level of asbestos fibres exposure to workers during improperly performed disassembly works of ACM sprayed products (non-friable)	PCM	An extrapolation considering the duration of exposure: 100,000,000	32
ACM (non-friable sheets) roofing removal and elevation area samples outdoors	The author's data: PCM + PLM	4000–6000	11
		500–1000	
Asbestos removal inside buildings (area samp.) in all construction: removing walls non-right, mostly steel, (non-friable)		1000–7000, aver. 2000	11,12
Removal of non-right a-c sheets from elevation ("personal sampling"), wrong, destructive technique		20,000–70, 000 aver. 2000	
Asbestos removal in all construction: removing walls (friable) non-right, mostly steel		7000–39,000 aver. 30,000	
Removing asbestos cords (friable)		17,000–51,000 aver. 34,000	
Removing asbestos cords (friable)		15,000–50,000 aver. 30,000	
As above, after the removal of friable ACM and after the final cleaning, before again use or after the beginning of use		Aver.860 med. 680	2,3
As above, after asbestos removal (non-friable) from walls, indoor air, all construction: non-right, wood or steel		300–800, med 500	11

Table 10. The chosen asbestos fibre concentration in indoor air in literature data with comparison to the author's data. s[1] TEM counted asbestos structures—fibres and fibre associations below the dimensions and geometries assumed for the respirable fibre [s/m^3].

than have been reported in similar cases in the literature[23]. These kinds of "critical condition samples" can range even from 50,000 to 20,000,000 f/m^3[35], most of them approx. 100,000 f/m^3 and higher, up to 600,000 f/m^3[23,38,39]. At the same time, many of the author's measurements in "asbestos buildings", without asbestos removal (normal operation), all constructions: non-right, mostly steel rigid or brick and forced concrete (friable + non-friable) had levels of approx. < 300–700 f/m^3, max 4600, med. 300 f/m^3[2–4,11,39]. The author's results obtained over many years are very close to those, presented in the literature on the subject of the asbestos airborne fibre during building use 100–500, max up to 6000 f/m^3[23,40,41]. A summary of the average levels of respirable (countable) concentrations of asbestos fibres in the air inside some typical Polish buildings in different conditions, during the use taking into account changes over time, are described in the articles[2,11,39]. They have similar literature results in a wide range of air pollution values < 300–5000 f/m^3.

The values reported by different researchers may vary significantly because they depend on the analysis and sampling techniques and the types of matrix in the ACM products. But why does one group of values (indoor air used building), requiring tests of great sensitivity, for the author's analyses, give similar values as in the literature? At the same time, the remaining two types of tests (indoor air during asbestos removal), requiring lower sensitivity with a much higher concentration of fibres at the point of destruction of ACM products, are at least a dozen times lower than the relevant literature data.

The answer leads to the thesis, that the reason for the lower (underestimated) values of asbestos fibre concentrations recorded during the works examined by the author is not the effect of the perfection of asbestos removal work, but their specific error of dismantling works.

Dispersion of asbestos concentration fibre in tests and spread of results

The basic inference from the literature data analysis showed that concentration values depend on the techniques and places of sampling and analytical methods used. The differences between these factors mean that only the results obtained using similar research parameters and places of sampling should be compared. But even then, undiagnosed factors can cause discrepancies in numerical concentration values. An example of differences in the concentration of asbestos fibre value in outdoor air using a similar technique of measure, but in different places, can be a comparison of monitoring of central Poland and Mashhad City, Iran. The first quoted data ranged in values from about 300 to 600 f/m^3[10]. The second one was measured with an average range of 11,400–14,400 f/m^3[33]. A comparison of such remote regions cannot ignore natural sources of emission and the types of asbestos associated with them[34].

It is generally accepted that higher concentrations of asbestos dust are generated during the destruction of friable than non-friable products and, of course, in a larger scale of product destruction. However, much also depends on other factors, such as the ability to disperse dust and the characteristics of the building itself.

A simple conclusion showing the relationship between the scale of damage and the concentration of asbestos fibres in the air is not obvious in every situation[11,34]. The concentration does not always correspond to the visual observation of the scale of ACM damage, because some parameters of emission are not measured or measurable (e.g. the time between ACM destruction and the air tests, degree of intensity of use of the room—which translates into vibrations and air movement enabling re-emission of settled dust). Those parameters (e.g. building features) are usually not recorded during sampling.

An example of significant differences in measured values may be differences noted in the exposure of workers involved in the disassembly of roofing (from 300,000 to 600,000 f/m^3) and facades made of asbestos-cement boards (below 100,000 f/m^3)[16]. This can reflect the differences in erosion factors of ACM (insolation, differences in rain erosion) and the resistance to weather conditions. In the case of dismantling works with asbestos-cement products, concentrations of 100,000 to 600,000 f/m^3 were recorded. In the case of improper removal of asbestos, even up to 100,000,000 f/m^3 were generated in the case of materials in form sprayed on construction. Workers in the finishing sector of construction are at risk of exposure to high concentrations of fibres. The air outside of their protective equipment has been shown mean and median exposure levels of 400,000 f/m^3 and 25,000 f/m^3, respectively. These levels have been found to range from less than 10 to 200,000,000 f/m^3, as analyzed by TEM[9].

For the author's research in areas of work, these values were much lower due to dust scattering in the larger volume of the unsealed work area. However generally, independent of method of asbestos removal work and method of contamination measuring, such values affect the air quality outside the work zone and can have impact to the health of residents, even if they are periodic. As per yearly averages, in buildings with friable asbestos, concentrations may vary irregularly. It is usually, less than 300–1000 f/m^3, but in some cases, exposure reaches 10,000 f/m^3 (fibres counted with an optical microscope)[35].

Information on health risks caused by low exposure levels

The author's data cited here generally refer to low levels of long-term user exposure to asbestos. Much of the literature on asbestos-related diseases presents low doses of exposure[35,42,43] which are currently under discussion. For example mesothelioma can develop even with low doses of exposure. However assessment of risk and its data are subject to high uncertainty due to the long (approximately 40-year) latency period. Estimating the long-term effects of low asbestos exposure can be calculated with a large scatter of risk values and an error[35] as other carcinogens in addition to asbestos may have an impact during this period. According to an assessment of the health effects of past environmental exposure to asbestos, at an exposure level of 9 fibres/m^3, the lifetime risk of mesothelioma can be expected to be one case per 100,000 people[44]. Others estimate such an effect at an exposure of 1000 f/m^3[37,8]. The consequences of environmental exposure may involve categories not included in the classic list of occupations at risk, where the problem of airborne spread of fibres from asbestos-containing materials remains primarily during routine maintenance or natural degradation[7,35,43]. Since the 1980s, the number of mesothelioma cases in ACM users outside the industrial manufacturing sector has increased. This has drawn attention to the risks associated with relatively low short time exposure but sufficient cumulative dose[29]. Non-occupational exposure to asbestos may explain approximately 20% of the mesotheliomas in industrialized countries[45]. The risk of mesothelioma from environmental exposures to asbestos (or exposure to asbestos contact in a non-asbestos work) is consistent with the response to fibre-type potency seen in the occupational setting[46]. Other estimates[47] propose 400–1000 F/m^3 give 0.4–0.9 mesothelioma cases each year per million persons from past environmental asbestos exposure.

Most studies provide calculations of the risk of developing cancer due to asbestos-related diseases based on the cumulative dose. Fibre concentration, duration of exposure and time since "first exposure" are parameters considered and incorporated in dose–response models, but they can change rapidly due to fiber dispersion, building ventilation and other circumstances that change during building use[2,4]. The author's data concerned short time slices therefore thise results cannot be used to estimate health risk directly. The effects of routinely accepted exposure values for residents in buildings with asbestos and in the general population (< 500 wł/m^3) according to ustalel[47] (" cannot be reliably quantified because they are undetectably low"). But levels several times (or more) higher in buildings with improper asbestos dismantling do not represent standard of exposure to asbestos for general population. In the case of staff and maintenance workers, these can be exposures close to occupational exposure sometimes. According to the mesothelioma risk studies cited, "the incidence is proportional to the concentration of fibres to which workers were exposed and the time since first exposure (…)."

The risk of low exposure and the effect risk of MM (Malignant Mesothelioma) is interesting discussed in[8] but that goes beyond the scope of this article.

Conclusions

1. The results of air pollution "area measurements" aimed at evaluating changes in outdoor and indoor air during asbestos removal are dependent on many factors and sampling conditions. As a rule, they are not able to reproduce the actual existing contamination levels in buildings during asbestos removal, lowering them as compared to the real values caused by the emission present.
2. The lack of sufficient negative pressure in the working area results in contaminants being dispersed throughout the building. It lowers the concentrations in the work area, transferring the contamination and hazard to other areas of the building and outside the building. This makes it impossible to reliably assess the effectiveness of the work.
3. When destroying ACM in a large room, the concentration of asbestos fibres varies greatly across its entire volume. The main reason is that the asbestos fibres are dispersed over a large volume. For the assessment of the state of contamination of such a volume, traditional sampling techniques are not representative, because the air that differs significantly in different parts of the room cannot be averaged (mixed) and the free access to the outside air lowers the asbestos fibre value at the place of its formation.

   In case 1, the excessive volume of the work area lowered and falsified the workers' exposure more than 60 times. For this reason, the "low concentration" values obtained from such "surface" measurements were unreliable for assessing the quality of work.
4. Reported indoor air research results from the work zone in the case of the lack of negative pressure, without documented sampling conditions and contractor working methods, can falsely suggest a high standard of work quality. In that case, there is a risk of obtaining "good results" from air testing which was made after poorly performed work.
5. In the outside air, the effects of faulty asbestos removal disappear fairly quickly when the work is stopped after a few hours or days (depending on the activity of the source of the contamination).
6. The concentration of asbestos fibres in the interior space of a building decreases with time. The course of the trend depends to a large extent on the air exchange in the building.
7. The measured concentrations of contamination from the facade or roof of such objects do not transfer from the sources at a distance of more than 10–15 m from them. However, people inside the building, regardless of the distance from the area of poorly performed work, may be exposed to the value 0.2 OEL (0.2×0.1 f/ml). In the case of large-scale destruction of ACM products in external walls and building facades, there is a risk of asbestos fibers leaking into the interior of rooms that are not subject to renovation. This may be caused by the exchange of internal air and the minimum distance of these rooms from dust emission sources or the tightness of windows.
8. Each disassembly of ACM-s temporarily causes a significant increase in asbestos pollution in the work zone and its vicinity. However, the asbestos removal process in a building does not affect the indoor air of adjacent buildings with closed windows, as the asbestos fibre concentration drops sharply with increasing distance from the source and over time.
9. The asbestos removal process is an activity with a high risk of asbestos dust hazard and should only be undertaken using the most effective environmental protection measures.
10. If improper removal of asbestos may cause contamination, it should be carried out under specialist supervision or, in the absence of appropriate opportunities, to abandon this work.

Data availability

All thematic data (in Tables 2, 3, 4, 5, 6, 7, 8) generated or analysed during this study are included in this published article [The supplementary raw data used in supplementary information files (Tables: A1, A2 and A3 in appendix A) are available from the corresponding author on reasonable request].

Received: 21 December 2023; Accepted: 20 August 2024
Published online: 11 September 2024

References

1. Kwak, K. *et al.* Environmental exposure to asbestos and the risk of lung cancer: A systematic review and meta-analysis. *Occup. Environ. Med.* https://doi.org/10.1136/oemed-2020-107222 (2020).
2. Obmiński, A. The natural reduction of threat in selected systems of old buildings containing asbestos. *Sci. Rep.* **12**, 2580. https://doi.org/10.1038/s41598-021-044877-y (2022).
3. Obmiński, A. Comparison of effects of use, protection, improper renovation and removal of asbestos products on the example of typical old buildings. *Sci. Rep.* https://doi.org/10.1038/s41598-023-37257-z (2023).
4. Obmiński, A. The concentration of asbestos fibres during building exploitation analysis of concentration variability. *Archiv. Civ. Mech. Eng.* https://doi.org/10.1007/s43452-021-003203-2 (2021).
5. Ervik, T. K., Hammer, S. E., Skaugset, N. P. & Graff, P. Measurements of airborne asbestos fibres during refurbishing. *Ann. Work Exposures Health* **67**(8), 952–964. https://doi.org/10.1093/annweh/wxad041 (2023).
6. Hajok, I. *et al.* Environmentally related diseases and the possibility of valuation of their social costs. *Sci. World J.* https://doi.org/10.1155/2014/284072 (2014).
7. Mossman, B. T. Fibre carcinogenesis and environmental risks. In *Environment and Prevention*, 241–55 (Ellis Horwood Ltd, 1991).
8. Gibbs, G. W. & Berry, G. Epidemiology and risk assessment in asbestos. In *Asbestos and its Diseases* (eds Craighead, J. E. & Gibbs, A.) (Oxford Univ. Press, 2008).
9. ECHA. Scientific report for evaluation of limit values for asbestos at the workplace Prepared by the European Chemicals Agency 1 February (2021).

10. Szeszenia-Dąbrowska, N. *et al.* Environmental asbestos pollution—situation in Poland. https://doi.org/10.2478/s13382-012-0003-0 (IMP, Łódź, 2016).
11. Obmiński, A. Asbestos in buildings, Scientific Studies, Warsaw (in Polish) (2017).
12. Obmiński, A. Asbestos in building and its destruction. *Construct. Build. Mater.* https://doi.org/10.1016/j.conbuildmat.2020.118685 (2020).
13. ITB Research Procedure PB LS-020/1/08-2006. Determination of the numerical concentration of asbestos-respirable fibres in building objects. Indoor air and atmospheric air. Optical microscopy method (in phase contrast and polarized light), 2006). PCA (Polish Center for Accreditation) Accreditation Certificate No. AB 023 (from 2006 up to 2022).
14. Chesson, J. *et al.* Interpretation of airborne asbestos measurements. *Risk Anal.* **10**(3), 437–447. https://doi.org/10.1111/j.1539-6924.1990.tb00527.x (1990).
15. Verma, D. K. & Clark, N. E. Relationship between phase contrast microscopy and transmission electron microscopy results of samples occupational exposure to airborne chrysotile asbestos. *Am. Ind. Hyg. Assoc. J.* **56**(9), 866–873. https://doi.org/10.1080/15428119591016494 (1995).
16. Brown, S. K. Asbestos exposure during renovation and demolition of asbestos-cement-clad buildings. *Am. Ind. Hyg. Assoc. J.* **48**(5), 478–486. https://doi.org/10.1080/15298668791385075 (1987).
17. Price, B., Crump, K. S. & Baird, E. C. Airborne asbestos levels in buildings: maintenance worker and occupant exposures. *J. Expo. Anal. Environ. Epidemiol.* **2**(3), 357–374 (1992).
18. Obmiński, A. Analysis of soil contamination with asbestos in antropopressive areas, library of the Faculty of Earth Sciences, University of Silesia, Sosnowiec, (Doctoral dissertation) (1998).
19. Hodgson, J. & Darnton, A. The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. *Ann. Occup. Hyg.* **44**(8), 565–601 (2000).
20. Noonan, C. W. Environmental asbestos exposure and risk of mesothelioma. *Ann. Transl. Med.* **5**(11), 234 (2017).
21. Rengyi, X. *et al.* Association between mesothelioma and non-occupational asbestos exposure: Systematic review and meta-analysis. *Environ. Health* **17**, 90 (2018).
22. TRGS 519. Asbestos Demolition work, repair and maintenance of asbestos-containing materials. Newsletter for the Rhineland-Wstwall (1993).
23. Database EV@lutil https://ssl2.isped.u-bordeaux2.fr/eva_003/.
24. Lee, R. J. & Van Orden, D. R. Airborne asbestos in buildings. *Reg. Toxicol. Pharm.* **50**(2), 218–225. https://doi.org/10.1016/j.yrtph.2007.10.005 (2007).
25. Burdett, G. J., Dewberry, K. & Staff, J. Airborne asbestos exposures from warm air heating systems in schools. *Ann. Occup. Hyg.* **60**(10), 27–39. https://doi.org/10.1093/annhyg/mev062 (2016).
26. Upton, A. C. Asbestos in Public and Commercial Buildings—A literature revive and synthesis of current knowledge, Health Effect Institute—Asbestos Research. Cambridge. https://www.healtheffects.org/publication/asbestos-public-and-commercial-buildings (1991).
27. Reynolds, S. J. *et al.* Factors affecting airborne concentrations of asbestos in a commercial building. *J. Occup. Environ. Hyg.* **55**(9), 823–828. https://doi.org/10.1080/15428119491018547 (1994).
28. Obmiński, A. Asbestos dust hazards during the dismantling of asbestos-containing products (indoors and outdoors), in Seminar: Risk assessment of buildings contaminated with asbestos dust and risk control methods. Warsaw-ITB, 13–14 October (2009).
29. Iwatsubo, Y. *et al.* Pleural mesothelioma: Dose-response relation at low levels of asbestos exposure in a French population-based case-control study. *Am. J. Epidemiol.* **148**(2), 133–142. https://doi.org/10.1093/oxfordjournals.aje.a009616 (1998).
30. Lange, J. H. & Thomulka, K. Air sampling during asbestos abatement of floor tile and mastic. *Bull. Environ. Contam. Toxicol.* **64**(4), 497–501. https://doi.org/10.1007/s001280000031 (2000).
31. Kakooei, H. & Normohammadi, M. Asbestos exposure among construction workers during the demolition of old houses in Tehran, Iran. *Ind. Health.* **52**(1), 71–77. https://doi.org/10.2486/indhealth.2012-0118 (2014).
32. Dumortier, P. & De Vuyst, P. Asbestos exposure during uncontrolled removal of sprayed-on asbestos. *Ann. Occup. Hyg.* **56**(1), 49–54. https://doi.org/10.1093/annhyg/mer096 (2012).
33. Moteallemi, A. *et al.* Monitoring of airborne asbestos fibres in urban ambient air of Mashhad City, Iran: Levels, spatial distribution and seasonal variations. *J. Environ. Health. Sci. Eng.* **18**(1), 1–8. https://doi.org/10.1007/s40201-020-00541-5 (2020).
34. Ilgren, E. B. *et al.* Kandovan the next 'Capadoccia'?—A potential public health issue for erionite-related mesothelioma risk. *Epidemiol. Biostat. Public Health* https://doi.org/10.2427/10106 (2015).
35. Pira, E. *et al.* Asbestos exposure: Past, present and future. *J. Thorac. Dis.* **10**(Suppl 2), 237–245. https://doi.org/10.21037/jtd.2017.10.126 (2018).
36. Lange, J. H., Lange, P. R., Reinhard, T. K. & Thomulka, K. W. A study of personal and area airborne asbestos concentrations during asbestos abatement: A statistical evaluation of fibre concentration data. *Ann. Occup. Hyg.* **40**, 449–466. https://doi.org/10.1016/0003-4878(95)00081-X (1996).
37. Dufresne, A., Dion, C., Frielaender, A., Audet, E. & Perrault, G. Personal and static sample measurements of asbestos fibres during two abatement projects. *Bull. Environ. Contam. Toxicol.* **82**(4), 440–443. https://doi.org/10.1007/s00128-009-9661-4 (2009).
38. Williams, P. R., Phelka, A. D. & Paustenbach, D. J. A review of historical exposures to asbestos among skilled craftsmen (1940–2006). *Toxicol. Environ. Health B Crit. Rev.* **10**(5), 319–377. https://doi.org/10.1080/10937400601034191 (2007).
39. Scarselli, A. *et al.* Occupational exposure in the removal and disposal of asbestos-containing materials in Italy. *Int. Arch. Occup. Environ. Health* https://doi.org/10.1007/s00420-016-1126-6 (2016).
40. SRC. Inc Denver. CO Summary of Published Measurements of Asbestos Levels In Ambient Air Prepared for USA EPA (2013).
41. Health Effects Institute, Asbestos in Public and Commercial Buildings A literature revive and synthesis of current knowledge. Cambridge Special Report https://www.healtheffects.org/publication/asbestos-public-and-commercialbuildings (1991).
42. Frost, G., Harding, A. H., Darnton, A., McElvenny, D. & Morgan, D. Occupational exposure to asbestos and mortality among asbestos removal workers: A Poisson regression analysis. *Br. J. Cancer* **99**, 822–829. https://doi.org/10.1038/sj.bjc.6604564 (2008).
43. Järvholm, B. & Englund, A. The impact of asbestos exposure in Swedish construction workers. *Am. J. Ind. Med.* **57**, 49–55. https://doi.org/10.1002/ajim.22264 (2014).
44. U.S. National Research Council of the National Academy of Science. Asbestiform fibres: Non-occupational health risks. (National Academy Press, 1984).
45. Goldberg, M. & Danièle, L. The health impact of nonoccupational exposure to asbestos: What do we know?. *Eur. J. Cancer Prev.* **18**(6), 489–503. https://doi.org/10.1097/CEJ.0b013e32832f9bee (2009).
46. Gary, M. *et al.* Non-occupational exposure to asbestos and risk of pleural mesothelioma: Review and meta-analysis. *Occup. Environ. Med.* **74**(11), 838–846. https://doi.org/10.1136/oemed-2017-104383 (2017).
47. Air Quality Guidelines for Europe Second Edition WHO Regional Publications, European Series, No. 91.

Author contributions

The corresponding author is also the sole author of the submitted article. The author declares that he is the sole author of the work. Therefore, he is also the corresponding author and responsible for all elements of the manuscript preparation. The percentage of the author's contribution to the development of all elements of the

manuscript (drawings, photographs, measurements, data analysis, preparation of the manuscript text) is 100% of the contribution.

Competing interests

The author declares no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-024-70631-z.

Correspondence and requests for materials should be addressed to A.O.

Reprints and permissions information is available at www.nature.com/reprints.