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Research Article

Evidence of Unrecognized Indoor Exposure to Toxic Chlorophenols and Odorous Chloroanisoles in Denmark, Finland, and Norway

Johnny C. Lorentzen,[1,2] **Lars-Erik Harderup**,[3] **and Gunnar Johanson**[1]

[1]*Institute of Environmental Medicine, Integrative Toxicology, Karolinska Institutet, SE-171 77 Stockholm, Sweden*
[2]*Centre for Occupational and Environmental Medicine, Region Stockholm, SE-113 65 Stockholm, Sweden*
[3]*Division of Building Physics, Lund University, SE-221 00 Lund, Sweden*

Correspondence should be addressed to Johnny C. Lorentzen; johnny.lorentzen@ki.se

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Production and use of chlorophenols (CPs) are being phased out around the globe, but with considerable lag in some highly populated countries. The process could be incentivized by leading countries sharing their experiences on problems that occurred, including the built environment. We previously reported that Swedish industry and authorities promoted CPs, including pentachlorophenol (PCP), as wood preservatives in buildings for decades. Yet, Swedish indoor research did not recognize exposure to the hazardous CPs and their odor potent derivatives, the chloroanisoles (CAs), which smell like mold and still evolve from legacy preservatives in damp building structures. We hypothesized that the toxic CPs and odorous CAs could be key players for health and odor problems not only in Sweden but also in the neighboring Nordic countries. We found no reports in scientific medical literature of CPs being used in buildings in these countries. However, grey literature shows that CPs were indeed used, even during building booms, in house exteriors, constructions, and interiors, from the 1950s up to the late 1970s (Denmark) and even the 1990s (Finland and Norway). One application of CPs was in houses erected on dampness-prone house foundations, conditions ideal for formation of odorous CAs through microbial methylation. Furthermore, our searches suggest that these problematic chemicals played hitherto unrecognized key roles when indoor air research evolved. Thus, odor became an important aspect of the "sick building syndrome" in Denmark and an early warning sign of health risks in Finland, as asthma and allergy were attributed to "dampness and mold." None of the countries addressed the possible links between odor and health effects and exposure to CAs and CPs. In conclusion, our results suggest that unrecognized indoor exposure to toxic CPs and odorous CAs has mislead Nordic indoor air research for decades.

1. Introduction

Wood preservatives based on chlorinated phenols (CPs), including pentachlorophenol (PCP), were once popular on a global scale and were socioeconomically important for the prevention of fungal and insect attack on valuable forest products. Today, PCP in particular is a recognized health hazard and classified as a persistent organic pollutant (POP) by the Stockholm Convention [1]. It is being phased out but with considerable lag in some highly populated countries, for example, Indonesia [2], Mexico [2], and India [3]. Applications of CPs in the built environment are likely being phased out in parallel, and countries leading these developments should share their experiences in the scientific domain. We have previously outlined some unfortunate circumstances around the use of CPs [4–7] starting in the early 1950s when PCP was presented to the American public as an odorless substance with many applications in buildings (Figure 1). Today, we know that CPs, through microbial methylation, give rise to very odor potent chloroanisoles (CAs) (Figure 1) that smell moldy [6, 7] and musty [8, 9].

Sweden has a major experience with the problematic CAs [4, 6, 7] because industry and government agencies promoted the use of CPs in buildings for decades. The CPs were

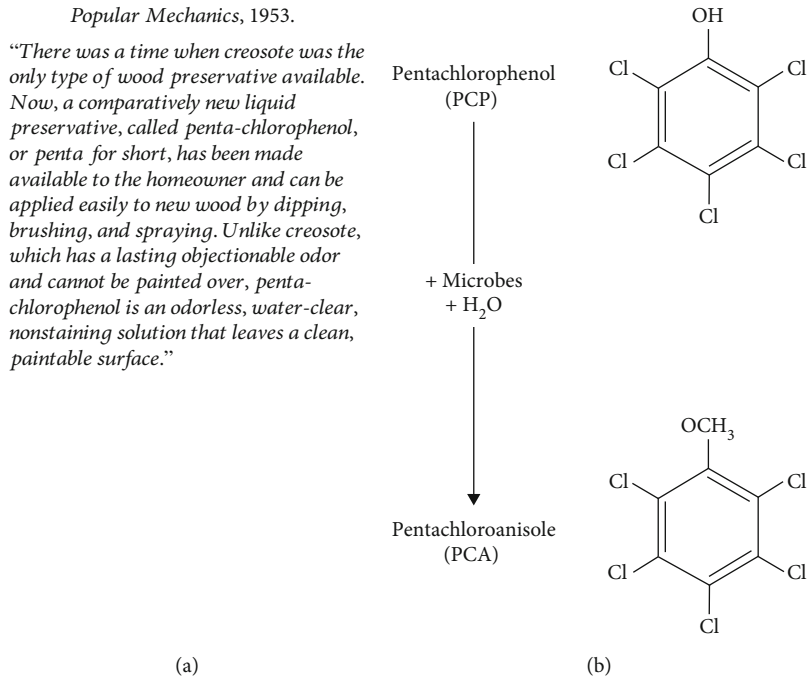

Figure 1: (a) An early quote on the usefulness of pentachlorophenol (PCP) [13]. In practice, PCP products also contained 2,4,6-trichlorophenol (TCP) and 2,3,4,6-tetrachlorophenol (TeCP). (b) Chloroanisole formation. Although the CPs are efficient pesticides, they do not completely sterilize and cannot hinder microbial methylation to CAs in the presence of humidity. PCP is converted to pentachloroanisole (PCA), TeCP to the more odor potent 2,3,4,6-tetrachloroanisole (TeCA), and TCP to the very odor potent 2,4,6-trichloroanisole (TCA) [6].

even applied in indoor paints. This practice continued until mass media raised health concerns, albeit focusing on dioxins and other highly toxic contaminants discovered in the CPs and their occurrence in the work and outdoor environment.

In 1978, a new indoor environment working group of the World Health Organization (WHO) met in Denmark. They mentioned four pollutants in building materials, namely, PCP, formaldehyde, radon, and asbestos [10]. Countries tried to handle the new situation to the best of their interests. In Germany, indoor PCP caused a major public stir [11, 12], whereas the Swedish public was unaware of such exposure. In Sweden, all licenses for products with CPs were withdrawn from 1979, after which government agencies neither recognized nor acted against the CPs that had already been used in buildings during the unprecedented building boom in the 1960-1970s [6].

At this time, new and newly renovated Swedish buildings had already started to smell. Even today, the typical CA odor can be found, originating from wood treated with legacy CPs and subsequently exposed to dampness in houses. Prominent examples are houses without cellars, built on concrete slabs directly on the ground with thermal insulation above the concrete, and crawl spaces with outdoor air ventilation. Swedish government agencies immediately attributed the odor in such houses to dampness and mold [14–16]. Today, government agencies do recognize CPs in buildings [17], mold odor from wood treated with CPs [17], and mold odor due to CAs [18, 19]. We argue that Swedish indoor air research has been, and still is, confounded by aligning with the initial stance of the Swedish government agencies and thus not recognizing the problematic chemicals. The confounding is particularly important to address in this case as it seems to have been widespread, long-lasting, and perhaps even ongoing. An American investigator remarked in 1981 that "People are very aware of indoor air pollution problems in Sweden and Denmark and are willing to pay whatever it takes to maintain a healthy indoor environment" [20]. We hypothesize that CPs and CAs could be unrecognized key players for odor and health problems not only in Sweden but also in the neighboring Nordic countries. Here, we aim to determine (1) if Denmark, Finland, and Norway used CPs in buildings, (2) if odor and health problems evolved, and (3) how the problems were interpreted.

2. Materials and Methods

2.1. Search for Information in International Scientific Literature. The PubMed and Web of Science databases were searched up to 10 May 2023, using the following search string: (chlorophenol* OR dichlorophenol* OR trichlorophenol* OR tetrachlorophenol* OR pentachlorophenol OR chloroanisol* OR dichloroanisol* OR trichloroanisol* OR tetrachloroanisol* OR pentachloroanisol) AND (building* OR indoor*). The wildcards (*) used to include plural forms in PubMed were omitted in the Web of Science search as plurals are automatically covered. Retrieved records were assessed to determine if they reported on CPs or CAs in Danish, Finnish, or Norwegian buildings. Further, PubMed was searched for information

on evidence for evolving odor and health problems and how potential problems were interpreted.

2.2. Search for Information in National Nonscientific Literature. Information search was explorative and guided by authors' prior knowledge, networking, and communications with government agencies, institutions, organizations, authorities, experts, and colleagues. Data were also retrieved from the World Wide Web and from the National Libraries of Denmark (Royal Danish Library, in Copenhagen: https://www.kb.dk/en) and Norway (National Library of Norway, in Oslo: https://www.nb.no/en). At the libraries, newspaper archives were searched for information from the 1930s and onwards. Further, data were retrieved from books, journals, magazines, documents on building legislation and practice, and government reports, for example, national surveys on contaminated sites and dioxin sources (sawmills, impregnation plants, building material waste, etc.). Data were also obtained by written requests to organizations and authorities. The search was explorative, covering texts in English, in Danish and Norwegian which are very similar to Swedish, and in Swedish which is a major minority language in Finland (many authority documents exist in Swedish as well). The search was not performed in Finnish, which is incomprehensible for a Swedish and English speaker, but authority documents in Finnish, provided upon request, were translated to English by a native speaker with expertise in indoor environment pollutants (see Acknowledgments). The search was guided by various words for dampness (for example, Swedish, fukt; Danish, fugt; and Norwegian, fugt), odor, mold, buildings, indoor, wood preservatives, wood rot, wood decay, CPs, CAs, various health effects, and names of people, institutions, companies, and products linked to retrieved results. In Results, we add contextual comments in parentheses when deemed necessary for readers understanding. Trade names are marked when we recognize them in documents that deal with CPs: (^{PCP1}) if they were registered in Sweden [6] and (^{PCP2}) if they were alleged to cause health problems in Germany [12].

3. Results

3.1. Scientific Evidence of CPs in Buildings and Interpretation of Evolving Odor and Health Problems. We found no papers in PubMed addressing any use of CPs in Danish, Finnish, or Norwegian buildings. Meanwhile, a Danish historical account [21] shows that odor and health problems did evolve around the time when CPs were used in Sweden. The account gives an eyewitness insight to how the problems were interpreted. In Denmark, a significant number of case stories were reported by occupants in modern Danish buildings erected during the postwar building boom of the 1950s. Asthma patients especially reported problems. The building boom was expected to continue into the 1960s, and the nature of the problems had to be identified. Odor research was insufficiently developed for practical use, and investigators initially, inspired by Dr. Yves Alarie's research on tear gas, focused on irritation [21]. In 1978, Denmark organized the first international indoor air quality conference, which led to the formation of a dedicated working group of the WHO [21]. One author of the historical account suggested the phrase "sick-building syndrome" ("SBS"), where a sick building makes people sick [21]. We found that this phrase was published by the WHO in 1983 [22]; symptoms were mainly reported from the USA and Scandinavian countries (our comment: Denmark, Norway, and Sweden). A second WHO report covering SBS was published in 1986 [23]. The Danish investigator contributed to both the WHO reports and also coauthored a conference paper stating that symptoms in "SBS" seemed to be described by sensory reactions in the first cranial nerve (odor) and the fifth (the common chemical sense) (our comment: odors and irritants) [24]. It was considered essential to create a dedicated journal to have results discussed, recognized, and published internationally [21]. A new journal was created, Indoor Air, and first issued in 1991. The Danish historical account, as well as others published in the Indoor Air journal, shows that Nordic/Scandinavian investigators had a profound influence [25–28] (see Supplement (available here)). In 2001, a Swedish chief editor of Indoor Air coauthored the most cited article in the journal [29], a Nordic interdisciplinary review on dampness in buildings and health [30]. It covered epidemiological studies on respiratory symptoms, asthma, and allergy. Visible mold and condensation on interior walls seemed to be rather rare in Scandinavia while humidity in the construction with indications such as bad odor seemed to be more frequent [30]. After 10 years as editor, the editor reported that Finland, Denmark, Sweden, Hong Kong, and Norway had published most, in relation to inhabitants [26]. Many Finnish studies, both before and after 2001, dealt with "dampness and mold" and respiratory health, and the studies were not only published in Indoor Air. For example, a Finnish editorial in Scandinavian Journal of Public Health states that mold odor is one of the first signs to warn occupants on health risks [31]. In 2017, the Swedish former chief editor reflected on the history of indoor air science (25) and noted that no causative microbial agents seemed to have been found (25). This is still a valid assessment. We note that early activities in this field, and coining of the "SBS phrase," occurred outside the scientific domain. We also note that several of the influential investigators represented supervisory government agencies or research institutes linked to such agencies (see Supplement).

3.1.1. Use of Chlorophenols in Denmark. According to historical accounts from major chemical companies, Denmark had successful pioneers in wood preservation and surface coatings who founded enterprises that became world-leading, for example, Gori [32], Dyrup [33], and Pinotex and Sadolin [34, 35]. The companies established trade names that are still known worldwide, for example, Gori ^{PCP1,2} [32], Dyrup ^{PCP2} [33], Pinotex ^{PCP1} [34], and Sadolin ^{PCP1,2} [35]. Companies rarely highlighted the chemicals being used, but an early advertisement from the company behind Cupran™ products specifically mentions PCP with excellent toxic effect for long-term conservation. This advertisement was one of many for preservatives in the 1956 supplement to GB3, a manual on building standards issued by the Academic

Architects Association [36]. The products were available at stores supplying/offering/selling timber and building materials and paints [36]. The updated GB4, issued in 1962, contains hands-on instructions against mold and mildew, including use of PCP in nonwaterborne solutions for pretreatment of wood and as addition to paint and use of sodium salt of PCP dissolved in water for washing of attacked surfaces and in waterborne paints [37]. Moreover, GB4 lists 10 wood preservatives approved by the Ministry of Housing, for applications at building sites and for dipping, brushing, showering, spraying, or brushing, including Xylamon [PCP2] and Solignum [PCP1] [37]. The use of CPs coincided with a building boom in the 1960-1970s, when many detached family houses were built [38], often on outdoor-ventilated crawlspaces that could have odor [39]. Some were not well insulated [39] (our comment: meaning that dampness might occur on cold indoor surfaces during winters even if rooms were heated, especially if ventilation was poor). A report from the Danish Ministry of Environment informs that there were few legal requirements to use treated wood, e.g., boards and timber in wet rooms. Still, it was praxis since the 1960s to use preservatives in many parts of the building, including the foundation [40]. A report from the Danish Environmental Protection Agency informs that PCP was used from around 1950 to 1977 for industrial wood preservation of windows and doors as well as for surface preservation and priming of wood before painting [41]. The report cites a Danish Wood Preservation Organization expert who made two key statements. First, that PCP was not used in indoor paints, as the PCP resulted in an obnoxious smell. Second, the expert stated that PCP-based wood protection dominated the market in the late 1960s and the early 1970s and that almost all types of wood preservation used in this period contained PCP, irrespective of brand, colored or noncolored, and industrial or private use [41]. The statement that PCP was not used indoors contrasts a large body of evidence. Thus, preservatives were promoted indoors in an information pamphlet from the timber trade in Denmark, which informed on chemical protection in 1963 and listed numerous products and companies. In some cases, it specified the toxic chemical, often a CP, and informed that a poison act prohibits indoor use of products with arsenic, with no such mention of CPs [42]. The pamphlet is cited in a 1967 newspaper article on how to protect wood best and most beautifully [43]. It promotes wood preservatives almost everywhere, including interiors if rooms were not continuously heated, and in constructions where the traditional constructive moisture protection should be complemented with chemicals, e.g., in foundations of houses without cellars. The article mentions several preservatives from the pamphlet and includes vacuum-impregnation examples, i.e., Konvac, Vacsol, and Sadovac (our comment: Sadolin Sadovac [PCP1,2]). Newspaper advertisements promoted the use of preservatives, also indoors (for example, Bondex [PCP1] [44]; Figure 2). Competition was fierce, and Gori stated that the main competing brands in 1965 were Solignum [PCP1], Pinotex [PCP1], and Bondex [PCP2], but in 1967, more than 90% of dealers switched to selling only Gori [PCP1,2] and kicked out competition [32].

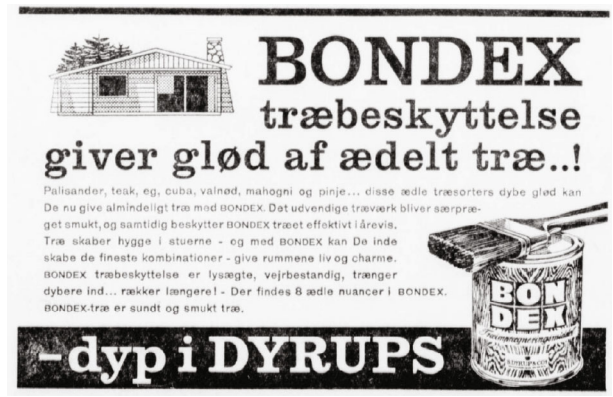

Figure 2: A newspaper advertisement promoting indoor use of Bondex [PCP1]. From Berlingske Tidende in 1964. [44]. The bottom line "Dip in DYRUPS" (translated) was a common advertising slogan in Denmark. The information includes the following translated sentences: "The outdoor wood becomes distinctively beautiful and at the same time, BONDEX efficiently protects the wood for years. Wood gives coziness to homes – and with BONDEX You can create the finest combinations indoors – give life and charm to the rooms."

Production sites became polluted; for example, when Carlsen and Plenge made a mistake in the production of Solignum [PCP1], the produce was simply poured out on the ground, according to an article from a local historical society in Copenhagen [45]. After the 1976 Seveso dioxin (TCDD) disaster in Italy, Danish newspaper articles dealt with the question if something similar could happen in Denmark. An official from the Environmental Protection Agency informed that Denmark did not use the congener of CP that may give rise to TCDD, and the dioxins that may evolve from PCP (under unfortunate circumstances) are not at all as dangerous [46]. PCP had been used in Denmark since the war, introduced by the Americans. It was now imported from England, Germany, and Switzerland, primarily used for wood preservation, but also in paints and glues [46]. PCP, by itself, did not pose any risk [46]. In the region bordering Germany, the German company Desowag-Bayer informed that health damage by their Xyladecor [PCP2] and Xylamon [PCP1,2] was not proven [47]. Outdoor environment scandals that involved CPs occurred in Denmark, but media focused on dioxins. In 1977, it became Danish regulatory strategy to limit dioxin contaminants in products, as described in a 1982 report of the Work Environment Institute [48]. The experts behind the report suggested to restrict the CPs, based on their evaluation that 2,4,6-triCP (TCP) could be carcinogenic. The report pointed out that "technical" PCP consists predominantly of TCP but often contains 4-12% of 2,3,4,6-tetraCP (TeCP) (our comment: these congeners are precursors to the most odor potent CAs).

3.1.2. Use of Chlorophenols in Finland. The TCP and TeCP congeners were extensively used in Finland. A paper from Building Information Ltd. (Rakennustieto Oy), owned by the Finnish Building Information Foundation, states that CP compounds were used in 1930-2000 and tetraCP until

1990, in adhesives in the plywood industry [49]. The most common product was Ky-5, which was used against superficial fungal growth (blue stain) on sawn timber. Ky-5 contained sodium salts of tetra-, tri-, and pentachlorophenol and was used for protection of timber by brushing, spraying, or dipping. It was manufactured until the mid-1980s. As a consequence, old sawmills have contaminated soils [49]. Regarding CPs in surface coatings, a 1958 report from the Finnish State Agricultural Research Board describes testing of products with PCP, namely, the American brand Woodlife and the Finnish brand Valtti [50]. Valtti became a major international brand in wood protection, and the manufacturer Tikkurila became one of the leading paint companies in Northern and Eastern Europe [51]. The company had problems meeting demands in 1962-1972, during a suburban construction boom in Finland [51]. In 1983, a paper in a national chemical journal stated that the main components of commercial surface smear agents, such as Valtti, Valtti colorless, Ventti colorless, and Ventti brown, were sodium salts of TeCP, TCP, and PCP [52]. One of the authors of the paper was given credit for having ended the production of PCP [53]. A report from North Savonia Environment Centre contains the information that an antiblueing agent containing CPs began to be used in Finland in the 1930s. Initially, the protective agent was imported from abroad, but in 1938, the Kymi Company developed a similar domestic product, which in the 1940s supplanted foreign preparations. The manufacture of Ky-5 was banned in Finland on 28 February 1984 after the discovery that the CPs are very harmful to both humans and the environment [54]. The Finnish writer Tove Jansson, famous in the Nordic countries for her Moomin troll stories, mentions Valtti in her book *Notes from an Island*, "Every summer there was the same wait for swallows. Brunström had told us that they nest only in houses where people are happy, but not if the house is painted with Valtti or Pinotex [PCP1]" [55]. Regarding how houses were built at the time, a Finnish educational material describes risk constructions for moisture, such as concrete slabs on the ground and outdoor ventilated crawlspaces [56]. The document also describes omission of a moisture barrier between impregnated wood and foundation concrete [56]. We have previously described the same disregard for traditional constructive moisture protection in Sweden [7].

3.1.3. Use of Chlorophenols in Norway. The Norwegian Building Research Institute referenced Swedish and Danish documents when instructing how to build houses without cellars, with concrete slabs on the ground [57, 58], or outdoor ventilated crawlspaces [59]. Norway was similar to Sweden regarding the use of wood and wood preservatives [60]. Surface treatments with PCP ended in the first half of the 1980s, but CPs were still used in Norway as late as 1991, according to the Norwegian Pollution Control Authority (Statens forurensningstilsyn, nowadays part of the Norwegian Environment Agency) [61]. It was mandatory to register products containing more than 5% PCP or TeCP, and three products were registered at the time [61]. We requested but were denied information on the identity of these products and their producers. One company imported and used a product against wood decay fungi in houses. A second company produced fiberboards for wet rooms using glue with preservative. A third company, a paint manufacturer, notified in 1988 that CPs had been discontinued [61]. Concerning paints, an author from the Norwegian Institute of Technology informed the public in 1961 about exterior painting of wooden houses [62]. The predominating wood stains and impregnation oils were the modern ones based on CPs [62]. Newspaper advertisements promoted products, e.g., Solignum [PCP1] by Carlsen and Plenge, emphasizing PCP [63] and recommending indoor use in text [63] or picture [64] (Figure 3).

4. Discussion

Our initial question was if Denmark, Norway, and Finland used CPs in buildings.

First, our searches in PubMed suggest that the use and presence of CPs in buildings in these countries have not been reported in the peer-reviewed medical literature.

Second, the grey literature describes substantial use of CPs in buildings, for example, against fungi on exterior and interior surfaces, and in constructive wood and boards. As all interior surfaces could be made of boards, these might have released significant amounts of semivolatile CPs to the indoor air. Further, being semivolatile, the CPs tend to migrate to colder parts in the building, locations that are prone to be damp. This may lead to formation of CAs also on untreated materials.

Third, building practices were similar in the Nordic countries and included construction designs, such as house foundations, that needed fungicides to counter weaknesses in moisture protection.

Fourth, these building practices were supported by the respective national authorities.

Fifth, the CPs were used during building booms in the 1960-1970s. People used many domestic products with CPs, such as Finnish Valtti and Ventti and Danish Bondex, Solignum, Gori, Sadolin, and Pinotex. In Sweden, Cuprinol was a major brand [6]. In addition, many nondomestic brands, for example, from Germany and the USA, were sold in the Nordic countries.

Sixth, it is sometimes difficult to connect CPs with manufacturers, products, and trade names, as such information can be protected by secrecy legislation. For example, this prevented us from identifying the Norwegian products registered in 1991 and the manufacturers. Such secrecy may partly explain why it was difficult to link health and odor problems to building materials and products.

Seventh, it is difficult to define the exact period when CPs were used in buildings. An earliest use around WWII is indicated in Denmark and even earlier in Finland, leading back to the USA. As a sidetrack, we traced the American products Santobrite and Dowicide in Sweden and discovered production of Swedish CPs (Pentolat) starting in 1942. This not only shows presence of CPs around a decade earlier than reported by us [6, 7] and the Swedish EPA [17]. It is also new that CPs were not only used but also produced. The

FIGURE 3: Part of newspaper advertisement promoting indoor use of Solignum [PCP1]. From Arbeiderbladet in 1962 [64]. The top line "SOLIGNUM is more reasonable than anything else" (translated) was a common advertising slogan in Norway. The information includes the following translated sentence: "It gives lasting protection and highlights the natural wood structure."

right to produce Pentolat was gained from Finland [65]. Evidently, the CP industry was international already around WWII. The latest use in the 1970s (Denmark) to 1990s (Finland and Norway) is indicated. However, existing product stocks might still be used, and import restrictions were probably not immediately or fully implemented.

Our second question was if odor and health problems evolved. The answer is yes. We show that odor and health problems incentivized indoor investigations, after WWII, by Nordic academics and government agency officials. Several investigators networked internationally at conferences and WHO meetings and were important in creating the Indoor Air journal where results could be published in a scientific setting from 1991.

Our third question was how the evolving odor and health problems were explained. We find that a major theme was the introduction of phrases that viewed people's symptoms through the status of buildings. The most prominent example is the "SBS" which translated into odor and/or irritation acquired in "sick buildings." In Sweden, the phrase "dampness and mold" was established in 1974-1982 to capture odor [14–16] and later also various health effects. We did not find examples of an earlier use of the phrase in the neighboring Nordic countries, albeit this cannot be excluded due to the difficulties of scrutinizing grey literature 80 years back in time in three countries. Furthermore, it may very well be true that "SBS" was conceived in 1982 as a Danish and American investigator strolled around during a WHO meeting [21], but the "sick building" phrase was already used in Sweden at that time [66]. Most likely, the "sick building" and "SBS" phrases were formulated in 1982 or just before.

Taken together, our results point to a strong socioeconomic incentive to use CPs in buildings and, as odor and health problems evolved, perhaps equally strong incentive not to recognize the CPs as a probable cause. One key statement in relation to odor is the Danish wood preservative expert who stated that PCP was not used indoors because it causes an obnoxious smell. We interpret this to mean that it was realized at some point that indoor use resulted in malodor after some time. Anyhow, we provide solid evidence that CPs were used indoors as well as in constructions; in both cases, they would be transformed into CAs in the presence of moisture (6). There is good reason to believe that industry was aware of pros and cons, in line with the mentioned key statement on obnoxious smell. For example, the Swedish Wood Preservative Institute produced a report in 1994, stating that CP-impregnated wood smelled like mold [67]. Furthermore, this report (accessible on-line) explained 20 years of odor problems in a neighborhood of "mold houses" as being the result of impregnated wood containing CPs. Besides odor, many residents also reported various health problems, including asthma and allergy [67]. In Sweden, it is well known among building investigators that Finnish "Kemi-houses" (our comment: the Kemi company previously included Tikkurila) imported to Sweden in the 1980s sometimes have odor problems due to CPs and CAs (personal communication, Anders Kumlin). Furthermore, one of our colleagues has personal experience of a house in Finland with odor. It was remediated by removing interior treated wood (personal communication, Pirjo Savlin). Compared to applications in building exteriors and constructions, the interior applications were particularly unfortunate, as they could result in direct dermal contact with CPs as well as higher concentrations of CPs in air and house dust, most likely leading to higher intake via skin, inhalation, and oral ingestion (children's hand to mouth). The CPs are readily absorbed via all three routes (63, 64).

We argue that the impact of toxic chemicals on people in buildings should not be viewed through the lens of building status, as this could prevent hazardous chemicals from being identified and subjected to proper exposure and toxicology assessment and thus hinder rational public health action and peoples' right to know of chemical exposures in their daily lives. Already in the 1980s, acute health effects of indoor exposure to CPs were described in toxicological reviews from the International Programme on Chemical Safety (IPCS) (63, 64). Concerning chronic health effects, unrecognized indoor exposure to CPs may have confounded studies focusing, for example, on exposure at work and through pollution of water and food. Even so, PCP is shown to have various chronic effects and was recently classified as a group 1 carcinogen by the International Association for Research on Cancer (IARC), with TCP being classified as a group 2B carcinogen (65, 66). It is essential to point out that CPs were not only used in damp conditions, and many people were likely exposed without ever sensing odor, or sensing odor after many years of exposure. We argue that Germany is a good example of proper handling of CPs in buildings, having implemented indoor air guide values for CPs that are still helpful when evaluating health effects, as exemplified by a recent publication on a school with odor due to CAs [9]. Remarkably, the nowadays notorious CAs were first highlighted in the high-impact journal Science in 1966, when an article on housing of poultry described sensory problems due to formation of CAs from CPs in wood shavings[68]. Despite this, the CAs were not recognized in housing of humans until relatively recently, apparently because the telltale odor and coinciding health effects were attributed to mold instead of CPs. Considering that CPs are being phased

out, whereas mold will always be present in buildings to some extent, it is important to stop confusing the two exposures.

Our finding herein that Sweden's neighboring countries used CPs in buildings is new from a medical and toxicological perspective. Accordingly, we found no prior records in PubMed, the most comprehensive biomedical database, which includes all records from the MEDLINE database. Indexing in MEDLINE was a major factor behind Indoor Air becoming a successful journal [25]. The use of CPs in buildings in the Nordic countries seems to have been neglected in other scientific domains as well, as we found no relevant records in the Web of Science, a database that covers all aspects of science and technology.

People were most likely exposed to several types of pesticides, but CPs were promoted for decades and are unique in their transformation to odorous volatiles in the presence of dampness and mold. Swedish grey literature studies show that mold on odorous impregnated wood is not visible but needs a microscope to be detected [67, 69]. Whatever the extent of mold growth may be, the CPs were not recognized by Nordic indoor air research. Since applications in buildings, like we describe herein, may still occur in developing countries [70], we argue that Nordic countries, some of the richest in a global comparison, should inform about their own uses and experiences of CPs. This would make a stronger case when advocating in the Stockholm Convention and other international fora to eliminate not only PCP but all CPs.

5. Conclusions

Our study highlights the major promise that CPs once held as pesticides, leading to their extensive use in buildings in Denmark, Norway, and Finland. Various applications in buildings seemed wise at the time, externally, in foundations and constructions, as well as internally, and this was supported by agencies and authorities during building booms in the 1960-1970s. At the time, houses were even built with designs that required use of fungicides against wood decay fungi in damp locations, such as foundations. We have previously reported on a similar development in Sweden. Altogether, our results show that unrecognized CPs and CAs provided impetus for Nordic indoor air research that became leading in the international arena, including the formation and editing of a specialized scientific journal. While adverse health effects associated with odor, substantial exposure to toxic CPs may have occurred without noticeable odor, or with odor evolving several years later. Our results add important perspectives to Nordic research on indoor air pollutants and suggest that research may be confounded, particularly when dealing with odor, as in "dampness and mold," "SBS," and epidemiological studies on asthma and allergy.

With respect to future research, we propose the following:

(i) Investigators should consider that CPs may be present in buildings, for example, when dealing with musty or moldy odor, which is typical of CAs

(ii) Reviewers and editors should be aware that investigators from countries where the presence of CPs and/or CAs in buildings was not recognized, or is not recognized, may fail to mention or consider these problematic chemicals

Data Availability

The data used to support the findings of this study are included within the article and the supplementary material file.

Conflicts of Interest

None of the authors declare any conflict of interest.

Acknowledgments

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Supplementary Materials

A supplement table summarizes data on Nordic investigators that had a profound influence on indoor air research at the time when CPs were used in buildings and later. *(Supplementary Materials)*

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