Moisture-dependent insects (silverfish species and psocid species (Psocoptera)) in modern buildings – a sign of hidden moisture and mould damages

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ABSTRACT

Through the last 10 years, it has been an increasing occurrence and activity of moisture-dependent insects in modern buildings. Grey silverfish (*Ctenolepisma longicaudata*) is the most common species, but it is also an increasing number of cases of silverfish (Lepisma saccharina) and *Ctenolepisma calva* (Mattsson 2018). Furthermore, several psocid species (*Psocoptera*), which is well-known for living in microclimatically humid constructions (>60% RH) feeding on mould fungi, is commonly found in modern buildings in frequency and number that is traditionally not found in older buildings (>30 years). The populations of these insects also survive for several years in the modern buildings. This shows that there are persistent humid areas in constructions where they have suitable hot-spots and access to suitable food. The humidity is due to residual building moisture and the moisture levels in such places are so high that there is a basis for growth for several species, such as *Aspergillus penicilloides* and *A. versicolor*. It is known that both mould spores and insect excrements can be allergenic.

Our results show that there is a clear pattern in the abnormal occurrence of mold in dust and air in buildings where there are plenty of moisture-demanding insects. Thus, does the occurrence of these insects represent a clear risk for a negative indoor climate exposure.

INTRODUCTION

The species *Ctenolepisma longicaudata* (often called grey silverfish, giant silverfish and long-tailed silverfish) was first described in South Africa in 1905 (Lindsay 1940) and has for a long time been found in countries with a warm climate, such as Australia (Lindsay 1940) and South-Africa (Heeg 1967). Through the last 20 years, observations of this species have been reported in several countries in northern Europe (Goodard et al. 2016, Lock 2007, Mannerkoski et al. 2010, Pape & Wahlstedt 2002, Schoelitsz & Brooks 2014). The species were observed for the first time in Norway in 2004 (Mattsson 2014, 2018). During the first years, the insect was only observed on rare occasions, but from 2013 the occurrence increased significantly (Mattsson 2018). Grey silverfish has in few years become a major pest organism in both Norwegian private homes and commercial buildings like offices, hotels, schools, shops, archives, and museums (Mattsson 2018b, 2018c). Currently, the grey silverfish is the most common insect species causing pest problems in Norway regarding the number of reported cases (Aak et al. 2018).

Two other silverfish-species, *Lepisma saccharina* and *Ctenolepisma calva*, has also proven to have an increased occurrence in Norwegian buildings through the latest years (Mattsson 2018a, 2018b).

Psocoptera is an order of insects with just over 80 registered species in the Nordic countries (Svensson & Hall 2010). Outdoors, they live in humid environments, often in dense bottom vegetation. According to the species database in Norway and Sweden, ten of the Nordic psocid species have been reported to have been found indoors in Norway (Svensson & Hall 2010). Several of these species were found repeatedly in Mycoteam's surveys of over 70,000 glue traps from more than 600 Norwegian buildings (see Mattsson 2018b). The results there shows that psocids mainly survive in basements, secondary floor coverings, carpets on damp concrete floors and similar places where there are stable humid conditions. 20-30 years ago, it was common to find psocids in new buildings ½ - 1 year after construction. As materials and structures gradually dried out when the building was taken into use and heated, the necessary moisture supply for the insects disappeared and when the relative humidity came below approx. 60% died quickly (Norwegian Institute of Public Health 2006, Mattsson 2018b).

Local moisture problems in modern Norwegian homes are in many cases related to residual building moisture in diffusion-tight constructions (Mattsson 2018c). Both modelling of humidity due to building physics and actual moisture measurements has shown that residual moisture can remain in the modern structures for many years after completion (Mattsson 2018b, SINTEF Community 2020).

Results from glue trap monitoring of more than 600 Norwegian buildings show that it is common to find psocids and other moisture dependent insects such as grey silverfish and silverfish in the areas of buildings that has a risk for residual moisture (Mattsson 2018b). The moisture dependent insects can for some period survive in dry conditions, but they need persistent high relative humidity above at least 60% RH for survival (Lindsey 1940, Heeg 1967a). At higher humidity values they have even better conditions both for survival and formation (Svensson & Hall 2010).

However, humidity is not enough for survival, proper nutrition must be available. Silverfish species can digest house dust and gain suitable nutrition from dust, but more nutritious food is even better. The main food source for psocids that occur indoors is mould spores (Norwegian National Institute for Public Health, 2006). In the wild, psocids mainly feed on decaying plant matter, lichen, algae, and fungi (Svensson & Hall 2010).

It is known that the presence of insects can affect the indoor air quality due to airborne fragments and excrement. In addition, the presence of mould in the excrements can lead to an extra load to the extent that these particles become airborne (Norwegian Institute of Public Health 2015).

In terms of health, it is well known that insect excrements can be allergenic. In addition, there is also published medical literature that shows that there is a clear connection between exposure of fragments from both grey silverfish, silverfish and psocids, and asthma / allergy reactions (Baldo & Panzni 1988, Barletta et al. 2005, Boquete et al. 2008, Fukutoma et al. 2012).

During monitoring and survey of grey silverfish, we have repeatedly been told that residents experienced increased asthma and allergy related health problems in homes where it was detected occurrence of many moisture-dependent insects (Mattsson 2018b). We have not had the opportunity to carry out any health examinations in these cases, so we do not have any direct clarification of the specific health problems. However, we have carried out various investigations and sampling of mould to clarify whether there were signs of the occurrence of established mould damage and a negative impact on the indoor climate in these randomly selected homes.

MATERIAL & METHODS

Site description

Mycoteam provides mapping of insect populations for private, commercial, and governmental buildings. The results presented in this paper is taken from glue trap mappings conducted between 2017 and 2021. Mapped sites include dwellings, townhouses, and apartments. Based on an initial survey of moisture dependent insects indoors from approx. 600 buildings, we have carried out an extended moisture survey of 74 homes where the presence of moisture dependent insects, mainly grey silverfish but also psocids, has been detected. The homes surveyed have been of different types, both detached houses and apartments.

The measurements have been made into constructions with suspected critical moisture values due to residual building moisture.

Glue trap mappings

The glue trap mappings were done in buildings where the inhabitants had observed insects (mainly grey silverfish) to document the size and extent of the insect population that was present. Therefore, the focus for most of the mappings presented in this study were the grey silverfish. The regular silverfish, *L. saccharina*, was registered when observed in the glue traps. Occurrence of psocid species was not initially systematically recorded, so they have not been included in the total study. The occurrence of moisture dependent insects, including psocids species were performed in six cases with a total of 286 5-6 years old apartments and detached houses.

Glue traps were evenly distributed in the building, and it was used approx. 1 glue trap per 2 m^2 of floor area. A Trapping index (TI) was calculated for all the mapped buildings and dwellings, and for individual floors within a building when possible. The Trapping Index is calculated with this formula:

TI = *No. of individuals / No. of traps used / No. of days traps were exposed * m^2 equivalent (400)*

Mould survey

Sampling has been adapted to what was appropriate in the building in question. Samples of moulds were taken in 73 buildings, while in one case extensive mould growth was observed on an indoor wall. Sampling methods included were sampling of material, dust samples extracted with tape (Mycotape), air sampling (Bioair and MicroBio) and DNA samples (Mycotape2). In 84 % (n = 58) of cases, visual observation of mould growth and one or several sampling techniques were used.

Mycotape2 is used for analysis of dust deposited on a horizontal surface. Sampling is intended as an indoor climate control as deposited dust must be assumed to have been in the indoor air. Identification and quantification of DNA from fungi in general, and selected moulds and actinobacteria is done by qPCR (quantitative polymerase chain reaction). DNA analysis of the dust is performed to assess the presence of fungi and certain bacteria (Streptomycetes). The method used identifies and quantifies various bacteria and fungi in the indoor environment, including species that are good indicators of moisture damage and growth of moulds in structures. The method is adapted to northern European conditions. Quantities and types of fungi in the dust are used in the assessment.

The assessment is based on a four-part scale that indicate deviations from what is expected. The scale is based on degrees of damage from the Norwegian Standard, Condition Analysis for Buildings, NS3424. The background for the assessment is based on Mycoteam's experience (Table 1).

Table 1. Overview of measures and consequences.

Degree of deviation	Deviation	Consequences	Measures
0	Normal	None	None
1	Small deviation	Small	Can be assessed
2	Medium deviation	Medium	Should be considered
3	Large deviation	Large	Measures must be taken

In this article we have combined results categorized as “normal” and “small deviation” in one group.

RESULTS

Occurrence of moisture dependent insects

In our glue trap mappings of in total 598 buildings and dwellings, the grey silverfish was present in 527. In 87 sites, both the grey silverfish and the regular silverfish were present (tab 2).

Table 2. Occurrence of silverfish and grey silverfish in 598 examined homes.

	No. of sites
Grey silverfish present	527
Silverfish present	151
Both present	87
Only grey silverfish	440
Only silverfish	64

In buildings where the glue trap mappings covered several floors (n=283), the trapping index (TI) were higher in the lowest floor in 230 (81 %) of the mapped buildings (fig 1). The lowest floor had a significantly higher trapping index than the floor above (Wilcoxon Signed Rank Test, p<0,05). The same pattern was observed for silverfish, where 23 of 26 buildings had a bigger trapping index on the lowest floor compared with the floor above (fig 2) (Wilcoxon Signed Rank Test, p<0,05).

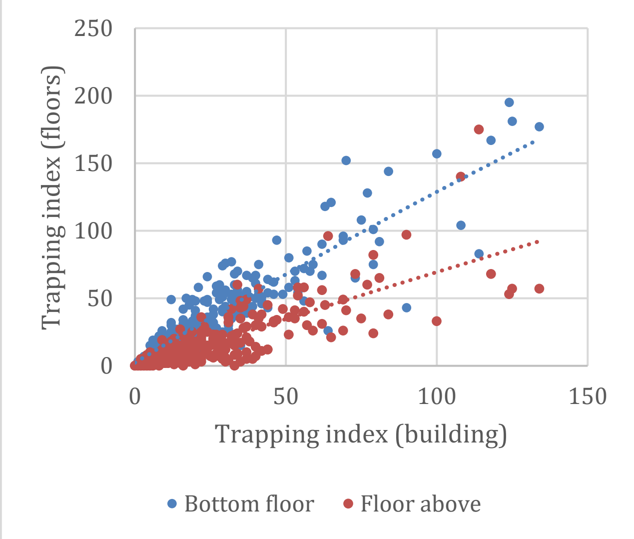

Figure 1. Trapping index for grey silverfish (*C. longicaudata*) on the bottom floor and the floor above.

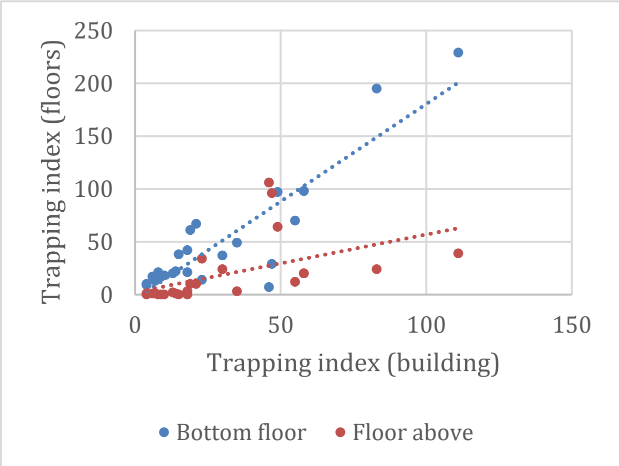

Figure 2. Trapping index for silverfish (*L. saccharina*) on the bottom floor and the floor above.

A survey of 286 apartments and detached houses showed that moisture dependent insects can be very frequently if the microclimatic conditions are favorable. In many of the examined homes both grey silverfish and psocids were common (tab 3).

Table 3. Results from survey of moisture dependent insects in 286 homes.

Building type	Age (years)	No. of homes	Grey silverfish (% of total units)	Moisture dependent species (5 of total units)
Apartment block	5	53	53%	91%

Apartment block	6	50	96%	Not analysed
Apartment block	5	52	69%	95%
Detached houses	5	54	74%	100%
Detached houses	5	20	86%	100%
Detached houses	3	57	84%	97%

Mould survey

In our follow-up inspection of 74 different homes (detached houses, terraced houses, block of flats), we have seen that in 18 (24%) of the cases there was no or little occurrence of deviating of mould-DNA values in the samples. In 17 (23%) of the homes there was a medium deviation and in 39 (53%) a large deviation of quantities and / or types of mould fungi (fig. 4).

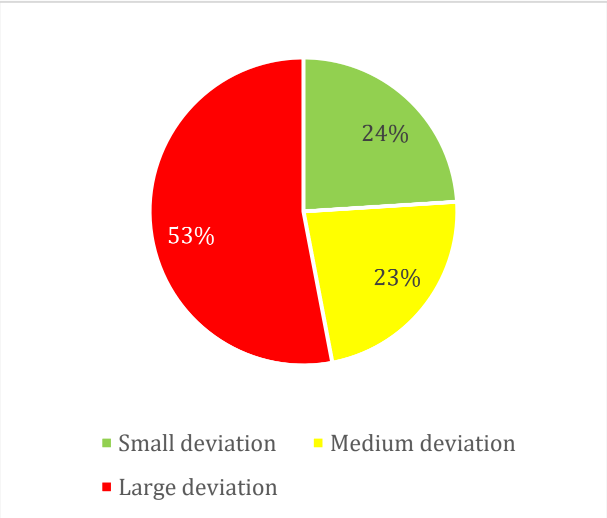

Figure 4. Results from mould sampling and observation of mould growth in 74 homes with documented occurrence of moisture-dependent insects.

An illustration on these results is shown from six similar buildings with extensive occurrence of grey silverfish and psocoid species. The analysis revealed that it was large deviations of mould-DNA in three buildings and medium deviations in the other three (tab 5).

DNA analysis of psocids from other homes has shown a clearly different occurrence of mould species - both in terms of species and quantities (tab 4). There were typical mould species such as that is well known for growth at moisture problems indoors.

Table 4. Example on mould-DNA in psocid individs that was catched on gluetrap in a modern dwelling. Green = small deviation, yellow = medium deviation and red = large deviation compared with a "normal" building.

	Individuals of psocoid species
Penicillium sp., *Aspergillus* sp., *Paecilomyces* sp.	
Penicillium chrysogenum	
Aspergillus versicolor	
Chaetomium globosum	
Stachybotrys chartarum	
Trichoderma viride	
Streptomyces sp.	
Cladosporium sphaerospermum	
Cladosporium cladosporioides	
Acremonium strictum	
Alternaria alternata	
Aspergillus glaucus	
Aspergillus niger	
Wallemia sebi	
Mucor sp., *Rhizopus* sp.	
Aspergillus fumigatus	
Cladosporium herbarum	
DNA all fungi	
DNA-profile overall assessment	

DISCUSSION

Distribution of insects

As the glue trap mappings have been done in buildings where the owner or inhabitant has observed insects and hired Mycoteam to document the population, the large share of buildings with an occurrence of either grey silverfish or silverfish is to be expected. In fact, only in 7 of the 598 mapped buildings, neither species were registered.

We did not carry out a systematic registration of psocid species in the beginning when we analysed glue traps. Eventually, when we discovered that there was a regular occurrence of psocids in the glue traps, they were also included in the analysis results. We have now seen that psocids have a similarly frequent occurrence in buildings as grey silverfish and they also occur in the same areas. Ecological studies on a laboratory population of the psocid *Liposcelis bostrychophila* showed that humidity levels beneath 60 % relative humidity is critical to their survival, and the optimal relative humidity is about 80 % (Wang et al. 1999). Occurrence implies by that reason important information about microclimatic conditions in adjacent areas and constructions (Baz & Monserrat 1999, Kort 1990).

Although moisture dependent species like the grey silverfish and silverfish to varying degrees can be found for a short time in different rooms and floors in connection with search for suitable food and possible microclimatically favourable habitats, they are dependent on having a hotspot in permanently humid environments. By that reason there is greater activity of these individuals close to these places.

Our data from mappings in buildings with more than one story clearly shows that populations tend to be bigger in the lower floors. This is expected since the diffusion-tight constructions with residual building moisture is found at least in the lowest floor, such as concrete floor on the ground and concrete floor dividers higher in multistore apartment buildings.

Mould as food source for insects

Grey silverfish can among other nutrition sources feed on mould fungi (Lindsey 1940).

Psocids are known to feed on fungi in the wild (Svensson & Hall 2010). The species *Liposcelis bostrychophila* has been described as a major household pest of farinaceous products in several countries (Turner, 1986), and one can rear psocids in a lab without adding fungi or yeast to the diet (see for example Opit & Turner 2009). However, Green & Turner (2005) showed that *L. bostrychophila* preferred a diet with yeast added to it and says that "*This provides evidence that booklice are associated with substrates contaminated with saprophytic organisms and fungi because they are attracted to these areas*." In addition, a diet consisting of wheat and brewer's yeast produced significantly higher population numbers for three *Liposcelis* species compared to other diets (Nayak & Collins, 2001). In our glue trap mappings, we did not see any pattern regarding the occurrence of psocids and areas such as kitchens or other rooms one expects to find starchy foods or farinaceous products. On the other hand, the psocids had the same occurrence pattern as the silverfish species (Mattsson 2018b).

Our analyses of intestinal contents on grey silverfish and psocids show clearly that they had a significant occurrence of several mould species. The detected mould species does not occur in dry buildings but are typically found in moisture damage indoors (Mattsson 2004, Mattsson et al, 2014).

Ecological studies of the Psocid species *Liposcelis brunnea*, *L. rufa*, *L. pearmani*, and *Lepinotus reticulatus* confirm that they are dependent of persistent high relative humidity above 60-65% relative humidity (Rees & Walker 1990). Several of these species have been detected in glue traps while monitoring grey silverfish in Norway. Psocids that lives indoors except for those who feed on farinaceous products, is known for a specific requirement for mould fungi as nutrition (Svensson & Hall 2010). Thus, the frequent occurrence of psocids strongly indicates occurrence of hidden mould growth in adjacent structures.

Mould, insects, and indoor air quality

The extensive mapping of moisture-dependent insects in the form of glue trap capture and microclimatic moisture surveys has clearly shown that they survive and multiply in connection with constructions that have a persistent relative humidity above at least 60% relative humidity. We have also seen that there can often be even higher moisture values from 75-80% RH and higher. Under such moisture conditions, there are favourable growth conditions for several mould species. In addition, it is likely that there may have been even higher moisture values during the construction phase and the first time afterwards in connection with a drying phase (Mattsson 2018b). It is possible that mould growth may also have occurred during this time.

In a normal, dry building, there is no growth basis for mould fungi. Therefore, unnormal amounts or types of mould are not expected when sampling in room air or deposited dust in such buildings. At sampling of mould fungi, it must always be considered that mould spores in samples may have come in from outdoor air, from local sources such as soil in flowerpots, mouldy fruit as well as from established mould damages in constructions. These spores can occur in both the air and deposited on surfaces. Species composition and extent of detected spores must therefore be assessed in relation to probable origin in each individual case. In our investigations, we have assessed proven values in relation to whether they have an origin in established mould damages or accidental occurrence.

In our follow-up inspection of 74 different homes (detached houses, terraced houses, block of flats), we have seen that in 18 (24%) of the cases there was no or little occurrence of deviating of mould values in the samples. In remaining 56 (74%) homes there was a medium or large deviation of quantities and / or types of mould fungi. This is a clearly deviating result in relation to the expected result if the origin of the mould from outdoor air or natural local sources. This clearly indicates that the source of the detected quantities and types of moulds is due to a spread from local areas with growth of mould fungi in adjacent structures.

Commonly found species, such as *A. penicilloides* and *A. versicolor* grows typically in areas with normal room temperature (20-25 °C) and a relative humidity of 78-85%. Such conditions are normally found under water barriers on concrete floors and adjacent parts of partitions and outer walls (Mattsson & Austigard 2014, Mattsson 2018c). Because these are areas that are not visible on normal inspection, any mould damage in such places will not be detected without destructive examinations. The consequence of this is that such mould damages remain undetected.

The examined buildings were relatively new (< 20 years old). They had all detected occurrence of moisture dependent insects, but no visible sign of moisture problems or mould damages. This should mean that one does not expect any deviating values of mould fungi in samples from there. Despite this, our analysis shows an unexpected deviations of mould spores and fragments in buildings with moisture dependent insects.

We have not done any evaluation of possible health effect of the detected amounts of mould, but we consider it likely that this may have a negative effect on the indoor climate.

The actual presence of the insects shows that there is a persistent moisture load in the constructions. They are thus a symptom of an underlying moisture problem that may include other issues such as the growth of mould and any physical and chemical effects on materials. Our recommendation is thus that the presence of moisture-dependent insects should be considered in indoor climate assessments. At the same time, the insects can be used as a possible warning sign that there are critical conditions regarding moisture and mould that should be investigated and possibly repaired to ensure a good indoor climate in the building.

In addition, it is well known that insect faeces can be allergenic (Baldo & Panzani 1988). There is also scientifically published medical literature that shows that there is a clear connection between exposure of fragments from both grey silverfish, silverfish and psocids and allergic reactions (Baz A, Monserrat VJ, 1999, Barletta et al. 2005, Boquete et al. 2008).

Building physics

The findings show that the grey silverfish and psocids have a more abundant occurrence in some parts of the building. Since the species has specific requirements to ecological conditions (Lindsey 1949, Heeg 1967a and 1967b, Kort 1990), and it is in the same area where most of the insect activity has been detected in our surveys (Mattsson 2018b). This occurrence helps us to interpret and understand minute details in humidity and temperature that otherwise can be challenging to understand (Mattsson 2018). This has also been described by Ntanos & Van Snick (2011), who discuss the importance of understanding the microclimate to predict risk for biodeterioration and understand the causes for established damage. Doyle et al. (2007) combines the characteristics of building physics and the actual collections that are stored in the building to define risk zones for various levels of risk for insect damage.

CONCLUSIONS

- Extensive occurrence of moisture-dependent insects in buildings shows that it is favorable moisture conditions in certain constructions in modern buildings.
- Analysis have shown clear deviation of mould-DNA in accumulated dust in buildings with many moisture-dependent insects.
- Although the presence of moisture-dependent insects does not directly say anything about the indoor air quality regarding mould fungi, one should be aware of the risk of this connection. Thus, one should be extra aware of the danger of a negative impact on the indoor air quality in cases of a rich occurrence of moisture-dependent insects in homes.
- To clarify whether there is a specific problem in such buildings, local investigations and assessments must be made.

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Figure 5. DNA-analysis of mould fungi in dust samples taken with Mycotape2 in six homes. Green colour represent small deviation, yellow = medium deviation and red = large deviation.

	A Hall	A Living room	B Hall	B Living room	C Hall	C Living room	D Hall	D Living room	E Hall	E Living room	F Hall	F Living room
Penicillium sp., *Aspergillus* sp., *Paecilomyces* sp.												
Penicillium chrysogenum												
Aspergillus versicolor												
Chaetomium globosum												
Stachybotrys chartarum												
Trichoderma viride												
Streptomyces sp.												
Cladosporium sphaerospermum												
Cladosporium cladosporioides												
Acremonium strictum												
Alternaria alternata												
Aspergillus glaucus												
Aspergillus niger												
Wallemia sebi												
Mucor sp., *Rhizopus* sp.												
Aspergillus fumigatus												
Cladosporium herbarum												
DNA all fungi												
Dust coverage %	**20,4**	**15,1**	**60,2**	**6,4**	**9,4**	**6,8**	**6,5**	**26,0**	**18,0**	**9,5**	**14,5**	**30,1**
DNA-profile overall assessment												