# Indoor Air Quality in Passive Houses: Methodology for assessment

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## Abstract

The tightening of buildings as a measure to save energy in the past is associated with indoor environmental quality problems later known as Sick-Building-Syndrome. The objective of this work was to establish a strategy and a methodology for assessment of indoor air quality in low-energy buildings (SMIL). The characterization of the indoor environment in newly built passive houses provides reference values for future assessments and/or eventual damage analyses. It is also a tool for evaluation of the indoor air quality with respect to current recommended guideline values.

In the initial phase of the project, five apartments were selected for a detailed monitoring of the indoor environment. The measured parameters were temperature, relative humidity, and concentrations of $CO_2$, $NO_2$, ozone, formaldehyde, volatile organic compounds and live microbiological flora. The measurements were conducted during the four seasons of the year, indoors and outdoors in parallel.

The study has resulted in a suggested methodology for the assessment of indoor air quality in low-energy houses. This methodology can be applied to any kind of building in order to document indoor air quality as part of the description of the building’s quality.

**Keywords**: indoor air quality, temperature, relative humidity, chemical air pollutants, mould spores

## Introduction

Dwindling fossil fuel resources and the threat from climate change, call for conservation and sustainable practices in all parts of society. The construction sector offers considerable potential in this respect. Directive 2010/31/EU of the European parliament and Council [European Union 2010] states that from the 1$^{st}$ of January 2021, all new buildings in the European Union should incorporate energy saving techniques and be ”near zero energy buildings” (nZEB). The trend towards complying with EU directive 2010/31/ is clear in Sweden. The fraction of low-energy dwellings in total national production in 2008 was 0.7%, 2.2% in 2009 and 7.2% in 2010 [Wahlström et al. 2011].Passive buildings, as defined by e.g. Sartori and Hestnes, 2007 and Badescu and Sicre, 2003 are a type of low-energy buildings exploiting e.g. efficient insulation and heat exchange techniques to reduce energy consumption for space heating. Other characteristics of passive buildings are their air tightness and that air exchange is achieved by mechanical ventilation, providing good control of the air change rate (ACR).

An economic analysis of energy savings in passive and low-energy houses compared to conventional houses has been performed [Audenaert et al. 2008], and showed clear economic advantages of passive houses, even when the higher investment and construction costs were accounted for. As expected, passive houses were more efficient than low-energy buildings in saving energy. Although the concept of passive houses is very attractive from the energy and economic points of view, it is also important to maintain good indoor air quality (IAQ). Indoor climate parameters such as temperature, relative humidity and $CO_2$ concentration were generally comparable and satisfactory in both passive and low-energy buildings [Mahdavi and Doppelbauer 2010]. Chemical aspects of IAQ in passive houses have received very limited attention.

Experimental multi-story apartment houses have been built in the neighborhood “Portvakten” in Växjö, Sweden, according to the voluntary Swedish passive house criteria [FEBY, 2009] using timber for the bearing construction. Prefabricated timber (solid glued wood) elements were used for load-bearing of inner and outer walls as well as for floors. The building, combining passive technology with wood material in a multi-storey construction, is unique although one similar wooden building has been erected in Berlin, Germany, with technical construction details described by Linse and Natterer, 2008. Energy and environmental performance of the building in Växjö - Southern Portvakten building – has been evaluated [Kildsgaard et al. 2013]]. The monitored total energy use was 47.6 kWh/m$^2$, excluding household electricity (revised to a normal year), which is considerably lower than the requirement of a standard building built today in Sweden—90 kWh/m$^2$. Also indoor air quality in the same building was evaluated by another research team. As part of the project “Stealth compounds in indoor air” funded by the Research council FORMAS, classical gaseous indoor air pollutants such as $NO_2$, ozone, formaldehyde and volatile organic compounds, particles and a semistable short-lived compound peroxyacetyl nitrate were measured in one empty apartment of the Southern Portvakten building [Fischer et al. 2013].

# Objective

The low-energy and passive houses have been more and more commonly established during the past couple of years. There is little knowledge about indoor environment and indoor air quality in such buildings. Within the project SMIL – Strategy and Methodology for assessment of Indoor air quality in Low-energy buildings, a selection of IAQ parameters were measured in five houses during all four seasons of the year. Here we present the preliminary results for one of the apartments and the methodology used for measurement and assessment of the IAQ.

# Method

## The building

The selected building is shown in Figure 1. The house was built 2009-2010. The apartment is situated on the first floor and has a floor area of 74 m$^2$. The floor is covered by Baltic Wood, the walls and ceiling are either panted by acrylic paint or covered by wall-paper. The total flow of the supply air is 39.9 Liter/second; providing the height of the rooms of 2.6 m, the Air Exchange Rate of the apartment can be estimated to 0.75 h$^{-1}$. Two adults are living in the apartment; they are non-smokers, have no children and no pets.

## Measurements

The measurements were performed during 2 week periods in winter (February), spring (May), summer (August) and autumn (November) of the year 2012. IVL's passive samplers for nitrogen dioxide ($NO_2$), ozone ($O_3$), formaldehyde and Volatile Organic Compounds (VOC) were placed centrally in the apartment for the indoor measurement and they were placed at a balcony to obtain the corresponding outdoor measurement. The formaldehyde samplers were DSD-DNPH Aldehyde Diffusive sampling Device (Supelco, Bellefonte, PA) and for VOC, Tenax adsorbent tubes (Perkin-Elmer) were used. The samplers were exposed for 12-14 days at each occasion and they were analysed for selected target compounds after returning to the laboratory. Temperature and relative humidity were monitored by a sensor (HOBO U12-012 data logger; Onset Computer Corp., USA). CARBOCAP® $CO_2$ monitors (GMW22, Vaisala, Finland) were used to measure the $CO_2$ concentration and it was logged using the HOBO logger. The measuring interval was 5 minutes.

$NO_2$ and ozone were analyzed by wet chemical techniques. Formaldehyde was analyzed, after eluting from the sampler, by liquid chromatography/UV detection. The VOC were thermally desorbed from the solid adsorbent and analyzed by gas chromatography/mass spectrometry and quantified as Total Volatile Organic Compounds (TVOC) in toluene equivalents.

Cultures of airborne fungal particles were collected on Rose Bengal agar media (agar strip HS; Biotest-Serum Institute GmbH, Frankfurt/Main, Germany) using a Reuter Centrifugal Sampler (RCS, Folex-Biotest-Schleussner Inc., Farfield, NJ, USA) during a 4-min sampling period (40 liters/min). Samples were collected inside (in the living room) and outside (on the balcony) of the apartment at exactly the same location at the four sampling occasions. After return to the laboratory, the strips were incubated at 25 C° for 7-10 days before microscopic examination. The numbers of cultivable airborne fungal particles were determined as colony forming units (CFU) per cubic meter of sampled air. The microflora was identified according to [Samson 1995].

# Results

In contrast to the ambient air quality standards, there are no legally binding limits for the quality of indoor air. The Swedish National Board of Housing, Building and Planning (Boverket) recommends that the air entering a building meets the national air pollution limit values for the ambient air. It is applicable to the air pollutants $NO_2$ and ozone, with the limit values of 40 $\mu g/m^3$ as annual average and 120 $\mu g/m^3$ as 8-hour average for $NO_2$ and ozone, respectively. The World Health Organization (WHO) provides recommendations on acceptable indoor concentrations of several air pollutants, among others formaldehyde, of 100 $\mu g/m^3$ as 30-minute average (WHO 2010). The State of California set even lower limit of 9 $\mu g/m^3$ of formaldehyde as chronic Reference Exposure Limit (REL). This value is based on positive associations between prolonged exposure to formaldehyde and allergic sensitization respiratory symptoms and decreased lung function (OEHHA 2008).

The German Federal Environment Agency (UBA) provides a more detailed list of chemical compounds and also an assessment of Total Volatile Organic Compounds (TVOC). Five levels were defined for the evaluation of TVOC concentrations and specific measures were recommended for each level. For the lowest level of 300 $\mu g/m^3$ of TVOC the Hygienic evaluation is “No objection”.

The results are presented in the following Tables and Figures. Figure 2 is an example of the temperature measured indoors and outdoors during the 2-week period in February 2012, and Figure 3 is the corresponding measurement of relative humidity. It is noteworthy that the indoor temperature in the apartment was remarkably stable at 21.5 ± 0.3 $^{o}$C despite the variations of the outdoor temperature, 2.3 ± 3.3 $^{o}$C (mean and standard deviation). Relative humidity indoor followed to an extent the outdoor variations; 27 ± 3 % vs. 68 ± 11 %. The concentration of $CO_2$ followed the presence and absence of people in the apartment and was on average at about 600 ppm; it never exceeded 1 000 ppm.

Figures 4 and 5 show the indoor and outdoor concentrations of $NO_2$, ozone, formaldehyde and TVOC. The concentrations of $NO_2$ were similar indoors and outdoors, as expected in buildings with no open combustion sources. Concentration of ozone indoors was substantially reduced compared to the outdoor levels; ozone is an unstable and reactive gas and it is decomposed on surfaces of the ventilation system before entering the indoor spaces. Both gases were present in the apartment at levels well below the ambient air quality limit values.

Indoor levels of formaldehyde at average value of 13 ± 2 µg/m$^3$ (average of all measurements) were very low compared to the WHO guideline (100 µg/m$^3$ for 30 minutes), however, somewhat elevated against the Californian REL. The indoor concentration of TVOC 135 ± 28 µg/m$^3$ (average of all measurements) was also below the lowest UBA level. Table 1 presents the individual measurements of TVOC and also comparison with the Southern Portvakten building [Fischer et al. 201]) and with the newly built Finish houses [Järnström et al. 2006].

The number of cultivable airborne fungal particles inside and outside ranged between 6- 455 and 12-1800 CFU/m$^3$ air respectively, see Figure 6. The outside mycoflora varied greatly between seasons of the year (Figure 7), which was also reflected in the indoor samples (Figure 8) as the mycoflora was in all similar inside and outside. Considering the numbers of CFUs and the mould families found there are no indications that mould growth constitutes any problem in this building. No water-indicating microorganisms were found in any of the samples [STM 2003, US EPA].

## Conclusions

The indoor air quality in the apartment in the passive building can be assessed as good with regard to the parameters taken into account in this study. Emissions of formaldehyde and volatile organic compounds were low. The outdoor air pollutants entering the building gave rise to acceptable concentrations indoors. Given the indoor/outdoor ratios it is important that the buildings are situated in areas without elevated ambient air pollutant levels. The microbiological samples did not indicate any mold damage in the apartment. It merely illustrated a normal inside and outside co-variation in numbers of live mold particles and mycoflora over the seasons of the year.

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**Figure 1** The passive house at Limonitvägen, Bromma, Sweden.

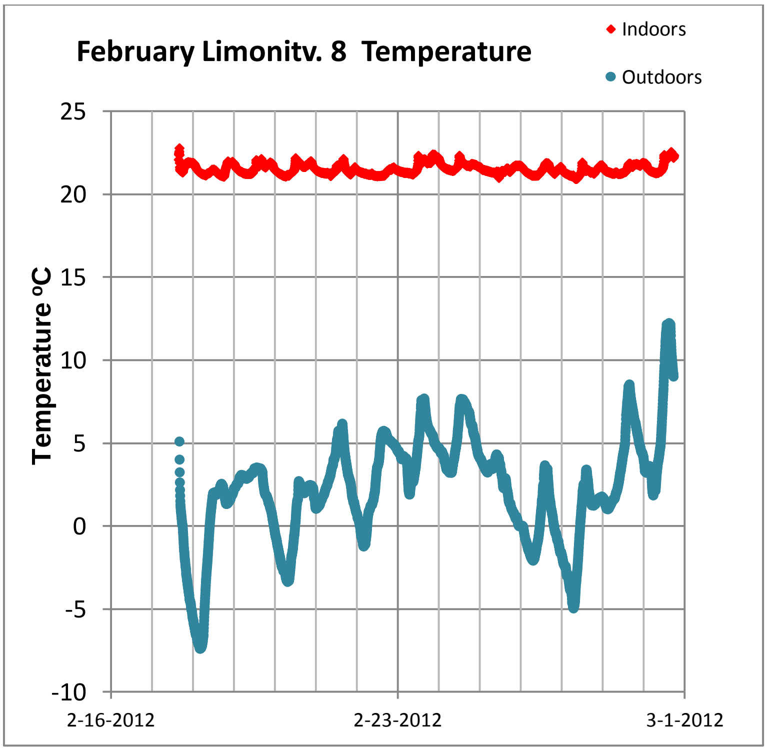


**Figure 2** Example of the mesurement of indoor and outdoor temperature.

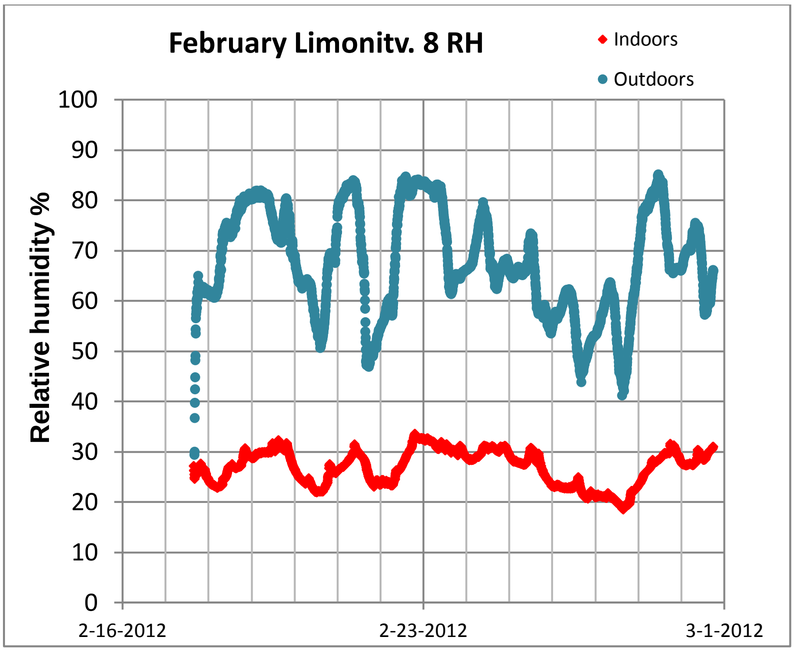


**Figure 3** Example of the mesurement of indoor and outdoor relative humidity.

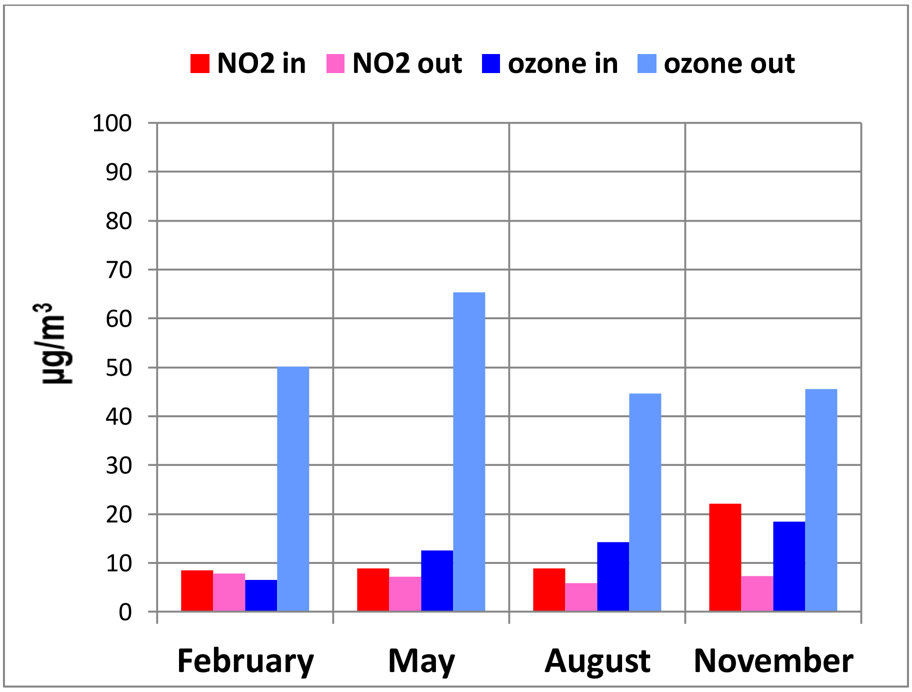


**Figure 4** Indoor and outdoor concentrations of $NO_2$ and ozone.

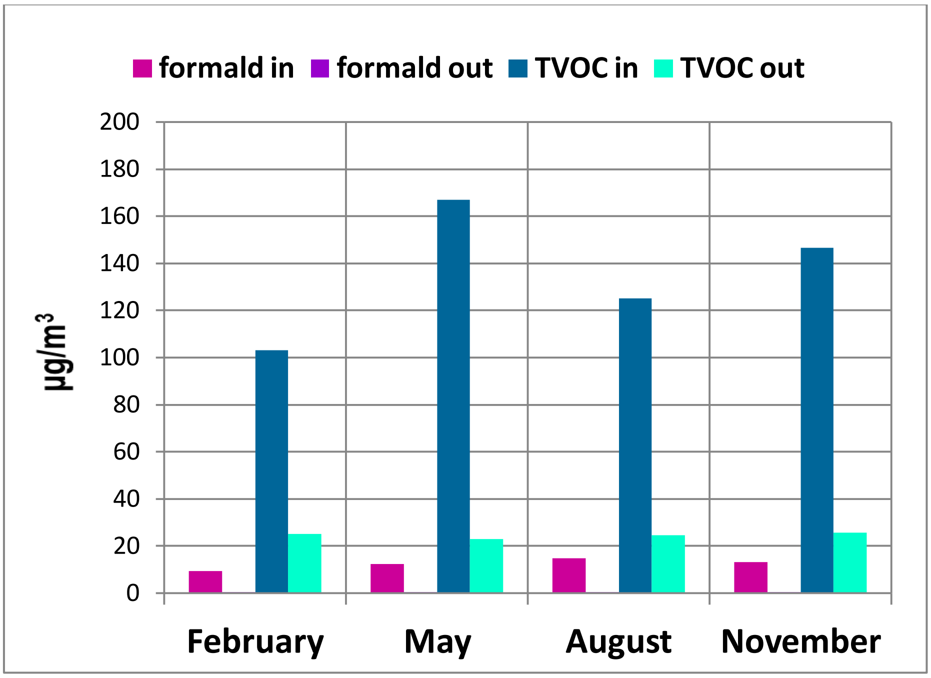


**Figure 5** Indoor and outdoor concentrations of formaldehyde and Total Volatile Organic Compounds.

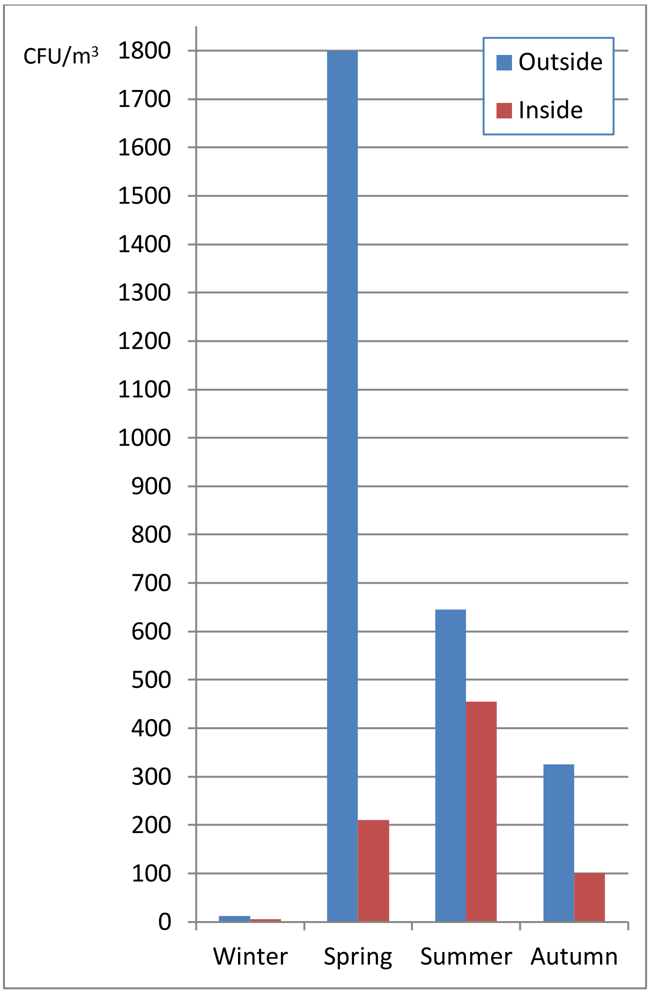


**Figure 6** The seasonal indoor and outdoor concentrations of colony forming units (CFU) of mould per cubic meter of samples air.

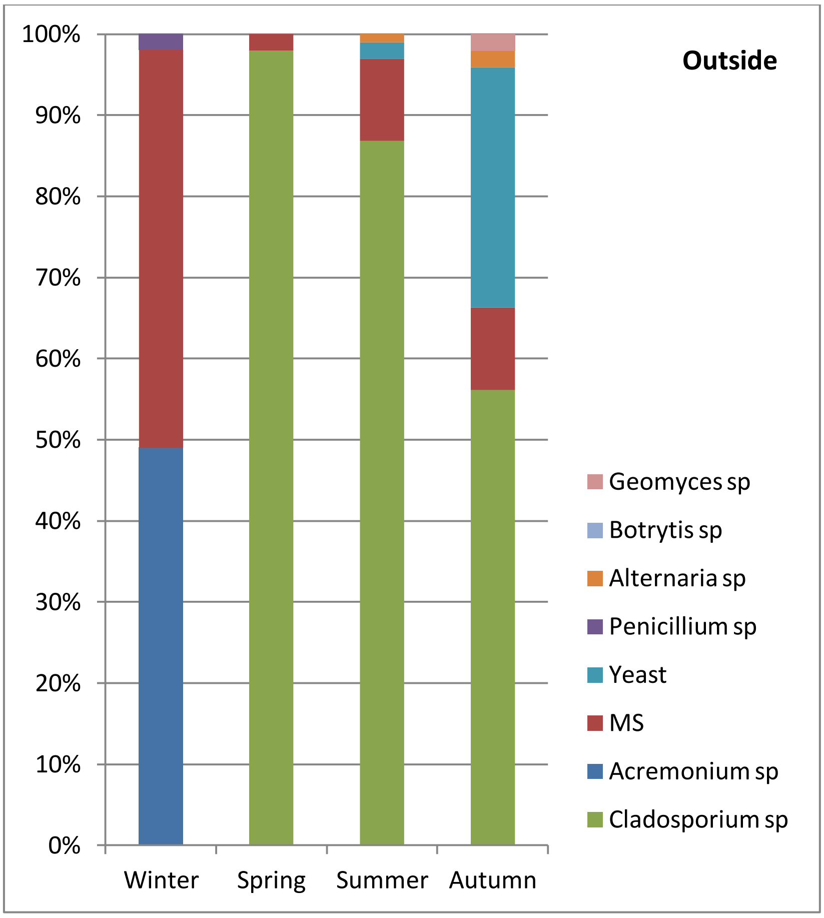


**Figure 7** The live mycoflora (composition of mould families) *outside* the monitored apartment. In the winter, spring, summer, and autumn the total number of CFU/m$^3$ were 12, 1800, 645, and 325 respectively. The Y-axis of this figure shows each individual mould family´s contribution to the total amout of CFU.

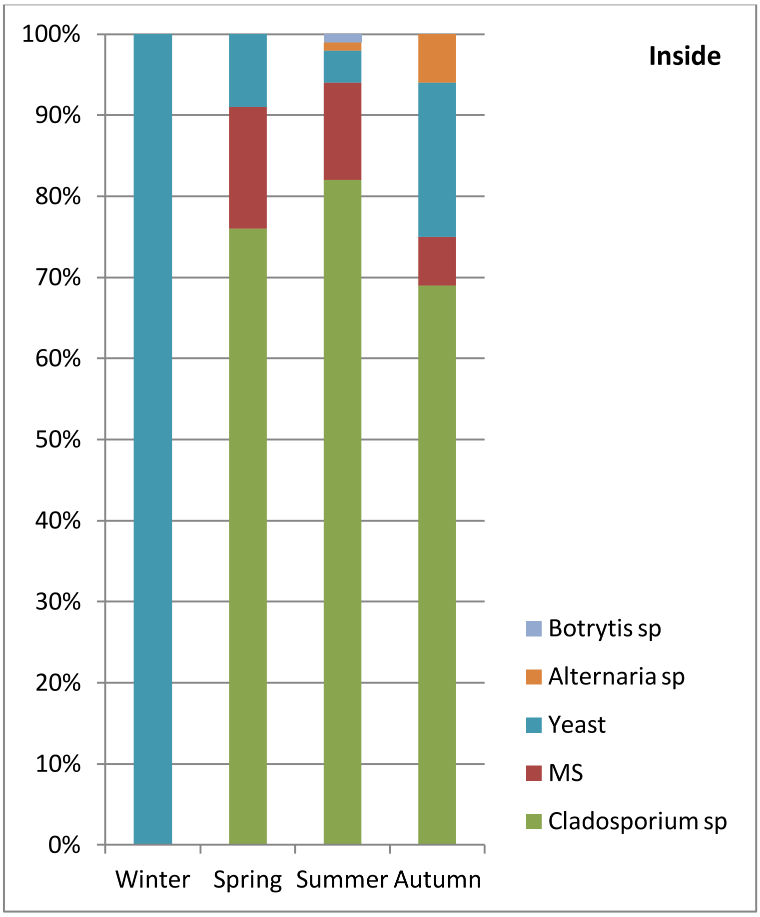


**Figure 8** The live mycoflora (composition of mould families) *inside* the monitored apartment. In the winter, spring, summer, and autumn the total number of CFU/m$^3$ were 6, 210, 455, and 100 respectively. The Y-axis of this figure shows each individual mould family´s contribution to the total amout of CFU.

**Table 1** Concentration of TVOC in the measured apartment during the seasons. Data from the Southern Portvakten building (Fischer at al., 2013) and from the new Finish buildings (Järnström et al., 2006) are presented for comparison togehter with the German indoor air guideline value for TVOC.

| | **Indoor TVOC µg/m$^3$** |
|---|---|
| Limonitvägen winter | 103 |
| Limonitvägen spring | 167 |
| Limonitvägen summer | 125 |
| Limonitvägen autumn | 147 |
| Fischer at al. 2013 | 150 |
| Järnström et al. 2006 | 247 |
| UBA guideline value | 300 |