Assessment of indoor air quality and hygrothermal conditions of boarders during autumn, winter and spring in two of Estonian straw-bale houses

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Abstract. Indoor air quality affects human health. These effects can be either positive of negative. Straw bale building has been claimed as a sustainable way of building.
The aim of this study was to evaluate indoor air quality in two of Estonian straw bale houses and provide solution of monitoring for indoor air quality and hygrothermal conditions of boarders as complex. Samples were collected between October 2014 til March 2015.
Sampling media and procedure was designed according to ISO standard 16000-18: *Detection and enumeration of moulds -- Sampling by impaction*.
Data loggers for collecting the data about CO_2, temperature and humidity were also used. Two of them (recorded temperature and humidity) were installed inside the wall (depth ~20 cm), the third logger was used as a desktop logger. We also collected some straw samples inside the wall to see which kind of microorganisms are living on them. Samples were plated, total colony forming units were counted and identified from the isolated colonies.
The results from air samples (CFU) were in one house higher than in the other one. Temperature, humidity and CO_2 levels were also higher in one house. This is probably affected by the different building characteristics (one of the houses is modular wall straw bale house, the other one is timber frame straw bale house).
Species, which we found, were similar in both houses. The most fungal genes isolated from samples were *Aspergillus*, *Penicillium*, *Alternaria* and *Cladosporium*.

Keywords: airborne fungi, indoor air quality, straw bale houses, indoor air, green building.

1 Intoduction

Brasche & Bischof [1] reported in their article that the overall mean time spent at home is around 15.7 hours. This time plays a critical role for persons exposure to environmental pollutants [2], so it is important that indoor environment will be healthy for living organisms.

Straw bales are used for building more than 200 years, first in Nebraska [3]. Straw is in most countries easily accessible, it is cheap and mostly usable (if there are no

weeds, which can cause rotting). According to Paist *et al* [4]) every year in Estonia approximately 125 tons of straw will be produced as a byproduct.

Straw has excellent thermal – and sound insulation properties as well it is a low energy process compared to other building materials [5]). Bales are fire resistance (rating F90) and normally the material is inflammable. [6]

Three common methods for building with straw bales are used. The traditional load-bearing method, frame and infill system and hybrid technology. There is also a method to build with modular wall panels. [7]

Indoor Air Quality is an important issue in the home environment. An inadequately ventilated home environment or a poorly designed ventilation system can lead to the buildup of a variety of problems with indoor air. [8]

The actual indoor temperature is the most important data to assess thermal comfort and indoor climate. Relative humidity (RH) and absolute humidity will also play an important role to indoor climate and hygrothermal design conditions. [9]

Mold exposures and dampness in buildings are common in buildings [10,11,12]. A major result caused by moisture damages is health effects on the occupants. The evidence of a causal association between dampness and health effects is strong, unfortunately the mechanisms are unknown [13].

Insufficient ventilation, inadequate insulation or water damage (leakage, pipe bursts) can lead to excess moisture in buildings and to a condensation of water on surfaces such as floors or walls [14]

The aim of this study was to evaluate indoor air quality in two of Estonian straw bale houses via collected data (air and material samples, data about CO_2, humidity and temperature levels) provide solution of monitoring for indoor air quality and hygrothermal conditions of boarders as complex

2 Material and Methods

The assessment of indoor air quality and hygrothermal conditions of boarders in two of straw bale houses was carried out between October 2014 til March 2015. Occupants were asked not to ventilate the houses 6h prior to measurements. Sampling media and procedure was designed according to ISO standard 16000-18: *Detection and enumeration of moulds -- Sampling by impaction* [15].

Microbiological air samples (collected with Microbio MB2 air samplers) were collected 3 times (during autumn, winter and spring time). Used air samplers were passing 100 l of air per sample. Sampling time was 1 min. A set of four air samples captured in each area was used to obtain average contamination values and representative results. The corresponding outdoor air was measured as reference value.

Sampling was carried out inside 1 m above floor level and outside 1.5 m above the ground. The sample plates were incubated at 32ºC for 72 hours and the colony forming units (CFU) were counted. Dichloran glycerol agar (DG18) and malt extract agar (MEA) plates were used as culture media.

Colonies from plates were recultivated periodically. The isolated microorganisms were plated with a spatula on the agar plates. The cultures were grown on the Petri dishes under 32°C.

Data loggers for collecting the data about CO_2 (about 1.2 m from floor level, measurement was taken after every 30 min)), temperature and humidity were also used. Loggers were installed indoors. Two of them (recorded temperature and humidity) were installed inside the wall (depth ~20 cm, height 1.5 m and 20 cm, measurement was taken after every 10 min)). To determine microbial growth inside the wall from each house two samples inside the wall were taken. Samples were plated, total colony forming units were counted and identified from the isolated colonies.

Air temperature and relative humidity in indoor air and inside the boarder was studied for evaluating the environmental conditions. It is known from mould growth index model [16] that some conditions are more suitable for fungi than others.

Monitoring of CO_2 enables to describe also the indoor climate but even more important is that the information about production and indoor-outdoor values enables to get an idea about ventilation presence and activity.

All chemicals and reagents (Fluka) used for this experiment were purchased from HNK Analüüsitehnika.

The identification procedure was performed via sample staining and microscopy. Bergey`s manuals and online databases were used for the identification.

3 Results and discussion

The characteristics of two buildings, which we investigated, are shown in table 1. Both of buildings have been built as post and beam constructions with wooden frame. In first building straw panels are used as insulation material, second building is a classical construction, where straw bales are placed into wooden frame as insulation.

Table 1. Characteristics of buildings

Characteristic	Building 1	Building 2
Indoor area (m^2)	200	250
Occupants	1	6
Bedrooms	1	3
Floors	1	1
Type of construction	Load bearing with straw panels	Load bearing with straw bales

The wall depth in both houses is the same – 60 cm, which consists of 50 cm of straw bale and 5+5 cm of clay plaster (both houses were plastered from inside and outside as well).

Indoor air quality is one of the main factors affecting productivity, health and well-being of people [17]. The results from air samples (CFU) were in one house higher than in the other one. Temperature, humidity and CO_2 levels were also higher in one house.

3.1 Indoor and outdoor air microbiology

Table 2. Seasonal variation in culturable airborne fungi on media MEA (malt extract agar) indoors and outdoors shown as mean and in parenthesis range of CFU $^{m-3}$ air

Sampling site and media	Autumn	Winter	Spring
Building 1 indoor (MEA)	503 (480-530)	460 (380-610)	153 (60-240)
Building 1 outdoor (MEA)	345 (300-380)	233 (200-280)	105 (80-160)
Building 2 indoor (MEA)	160 (100-220)	158 (100-250)	140 (100-160)
Building 2 outdoor (MEA	278 (220-320)	113 (100-130)	70 (60-80)

As seen from the table 2, indoor MEA CFU counts are in both buildings higher as in outdoor air. Moisture content inside the bales is important for the microbial activity [18]. Due of the higher moisture content microorganisms can activate from spores and will start growing again. In these two buildings growing conditions for microbiological life are good during almost all the time. Autumn indoor readings from the first house were probably higher because of the mold spots found from bedroom outer wall.

DG18 plates had a little growth from outside air (less than 20 CFU per plate). Indoor DG18 air sample plates had only few colonies (max 5 colonies per plate). All the colonies from outside were identified and indoor identified species corresponded to outdoor ones.

In normal and healthy building the majority of fungi come from outdoor sources [19]. Total number of air fungi is always lower than outdoors [20]. In both of our buildings the total number of air fungi indoors was greater than outdoors. We found a fungal growth from a north side corner of a bedroom. Growth was identified as a member of *Cladosporium* family. Homeowner used a fungicide which we suggested (Biotol© spray, which is effective against mould growth [21]) multiple times and added a coat of fresh clay plaster. This problem had not reported again until now.

In second building we did not found any visible mould spots, but the owners claimed there was a small pipewater leakage for few hours in early summer 2014 – before when we started our monitoring process. Combained with temperature (2014 was a hotter summer than normal in Estonia [22] it might be the case why there was more fungi present in inside. We also took some new air samples in autumn 2016 and in indoors CFU was lower than outdoors.

Viitanen [16] has been reported that for mould development is the ideal environment with temperatures from 20 to 28ºC and relative humidity more than 55%. In our case we have temperatures and RH% lower than reported before, but still we can see some indications of microbial activity.

Species, which we found, are quite common in outdoor air [19, 23, 24] and were similar in both houses. During autumn was the most abundant fungi from genus *Cladosporium*, followed by *Alternaria*, *Penicillum*, other fungi and *Aspergillus*. Most common genus in indoor air during winter was *Penicillium*, followed by *Aspergillus* and other fungi. During the spring the main genus was *Cladosporium*, followed by fungi from genus *Penicillium*, *Aspergillus*, others and *Alternaria*. Some of the species can be harmful to human health by the ability to produce mycotoxins [25].

3.2 CO2, relative humidity, temperature indoors

Table 3. CO_2, relative humidity and temperature levels of buildings with standard deviatation

Sampling site	CO_2 (ppm)	RH (%)	Temperature (ºC)
Building 1	569.7±164.1	31.4±5.1	18.8±1.2
Building 2	681.1±130.3	36.6±3.1	19.1±1.2

CO_2, relative humidity and temperature levels of buildings are shown on table 3. In first building the mean CO_2 level was 569.7±164.1 ppm. Mean temperature was 18.8±1.2 and mean RH was 31.4±5.1%. In second building the mean value of CO_2 was 681.1±130.3 ppm. Mean temperature was 19.1±1.2 and mean level of relative humidity was 36.6±3.1%. Indoor vapor content in first building was on average 5.1 g/m^3, in second building 5.9 g/m^3. These levels are suitable for good thermal comfort in bedrooms [26].

Carbon dioxide concentrations in both buildings over a same 24 hours period has shown on figure 1. All the other measured days were similar. Carbon dioxide levels are similar an hour before midnight, but differ a lot during night and day time. On building 2 this measured bedroom was also a playroom for children during daytime, thus greater CO_2 readings. The owner from building 1 was away from bedroom during daytime and therefore are also lower the CO_2 readings.

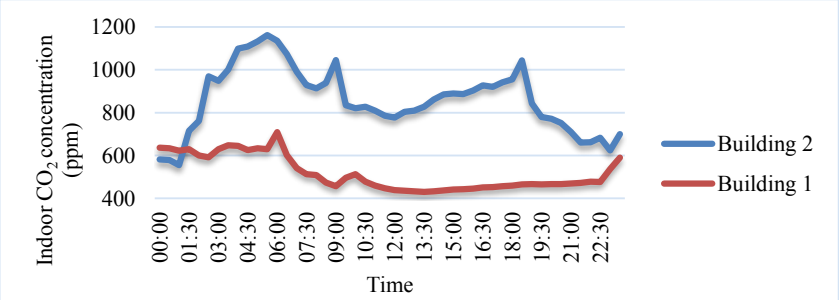

Fig 1. Carbon dioxide concentration (ppm) dynamics over a 24 hours period in buildings

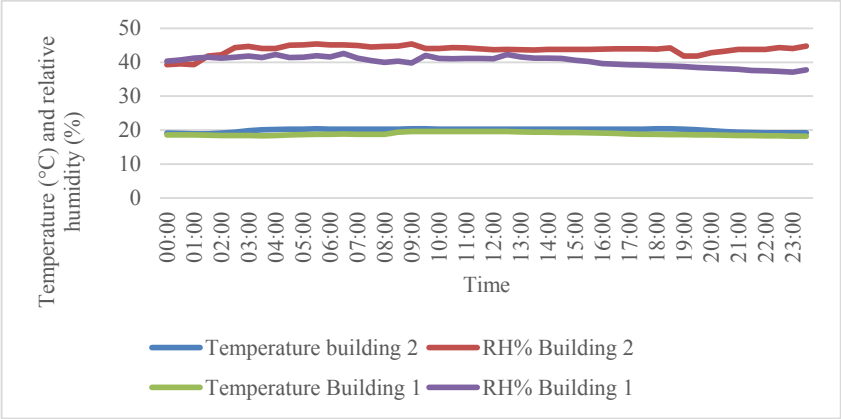

Fig 2. Temperature (°C) and relative humidity (%) dynamics over a 24 hours period in buildings

On figure 2 are shown temperature and relative humidity dynamics over a same 24 hours period than on figure 1. Relative humidity is higher in second building, temperatures in both buildings differ only a little.

Several factors can affect bedroom air quality and sleep comfort. A major group of these are related to thermal comfort. [27] A common indicator of indoor air quality is CO_2 concentration. Presence of CO_2 are connected with human metabolism and respiration. It has been found earlier that elevated indoor carbon dioxide levels (1000-4000 ppm) increases sick building syndrome (SBS) symptoms, but no direct link had not been found. [28,29,30]. On the figures are shown carbon dioxide concentration dynamics during a 24 h period, measurements were made twice in an hour. CO_2 concentration in first building is higher during nighttime. From fig 2 we can clearly see the room airing before sleep which will lower the CO_2 concentrations during night-time (fig 2).

To calculated the ventilation air flow in the room. We used a calculation as follows [31]:

$$Q = \frac{G}{C_{In} - C_{out}}, \qquad (1.1)$$

where: G – emission of CO_2 in the room mg/s,

Ci_n – indoor CO_2 concentration mg/m3,

C_{out} – outdoor CO2 concentration mg/m3.

For building 1 bedroom the airflow was 122.4 m^3/h (34 l/s) and for second building bedroom it was 72 m^3/h (20 l/s). Both of these levels are much higher than required [31] and both of our buildings are belonging to the highest class of indoor climate [32].

3.3 Relative humidity and temperature inside the wall

We used two loggers to get data from inside the wall. Results of our measurements are shown in table 3.

Table 3. Relative humidity (%) and temperature (ºC) inside the wall with standard deviatation

Sampling site	RH (%)	Temperature (ºC)
Building 1 upper logger	44.8±2.3	15.5±2.4
Building 1 lower logger	49.5±4.3	10.1±3.5
Building 2 upper logger	35.9±3.1	19.4±1.5
Building 2 lower logger	34.4±4.6	15.9±2.1

Relative humidity level inside the wall were on average. In second building, where was the water leakage, levels of relative humidity are lower than in first building. We assume it is so due higher temperature and room airing.

4 Conclusions

In literature is a limited database for straw bale buildings in northern hemisphere, but they are highly requested, because the interest for building with renewable materials is increasing in time.

An experiment to evaluate indoor air quality in two of Estonian straw bale houses and provide solution of monitoring for indoor air quality and hygrothermal conditions of boarders as complex was carried out from autumn 2014 til spring 2015 in Northern part of Estonia. Two straw bale buildings were monitored.

Mean values of CFU (higher during autumn and spring, lower during winter) and species we found were similar in both cases. There was a seasonal difference between airborne fungal species. Most of found species can present a health risk for humans, especially are endangered elderly people and children, also persons with weakened immune system, respiratory diseases and allergy.

CO_2 concentration levels were in both cases on lower end of the scale, temperature and humidity levels were on comfortable range.

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