MICROBIAL GROWTH IN INSULATION OF EXTERNAL WALLS: MODELING THE INDOOR AIR BIOCONTAMINATION SOURCES

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ABSTRACT

We studied microbial growth inside exterior walls as a possible biocontamination source for indoor air. Microbial contamination (mesophilic fungi, actinobacteria and other bacteria) of the insulation layer was measured in cfu/g of mineral wool. Quality of indoor air was studied from flats next to analysed panels having different degree of microbial contamination in the insulation. Generalised Linear Mixed Models were used to analyse indoor air spora using microbial contamination of insulation, other microbial sources (e.g. outdoor air), and environmental variables as explaining factors. Actinobacterial contamination in the insulation layer was shown to affect indoor air quality. An analogous linkage with other bacteria or fungi was not found. The moisture content of indoor air (g/m^3) affected significantly airborne counts of all three microbial groups.

KEYWORDS: air quality, actinomycetes, modeling, insulation, humidity , bacteria, microbial growth, wall, convection

INTRODUCTION

Indoor air biocontamination from fungi, actinobacteria or other bacteria - and its effect on human health is widely established [e.g. 1]. Role of microbial growth on internal structures or in HVAC-systems as an indoor air contamination source is evident. When the source finds place inside an external wall of the building, there might not be a direct contact with the indoor air. E.g. the type of the wall structure affects air convection.

Concrete sandwich façade panels (Figure 1) in building frameworks have been generally used in modern apartment buildings in Scandinavia since 1960's. They are composed of two rein-forced concrete panels enclosing a mineral wool thermal insulation (mainly rock or fibreglass wool). In a previous study [2] we have shown that microbial growth was found quite infrequently in the insulation layer and distinct contamination was related to the panel condition.

Due to pressure ratio in ventilated buildings, microbial contamination in the insulation layer may affect indoor air quality, if supply air flow is drifted trough the contaminated wall structure (Figure 1). The aim of this study was to evaluate the effects of microbiologically contaminated insulation on indoor air quality.

METHODS

We studied inhabited apartment buildings of 2 to 38 years in age in the southern coastal area of Finland (detailed data [3]). The external walls were sandwich panels. Ventilation system of

Examples of possible air convection routes through contaminated insulation layer

External concrete slab
Internal concrete slab
Concrete grout (possible cracks)
Floor structure
Insulation layer (possible microbial growth)
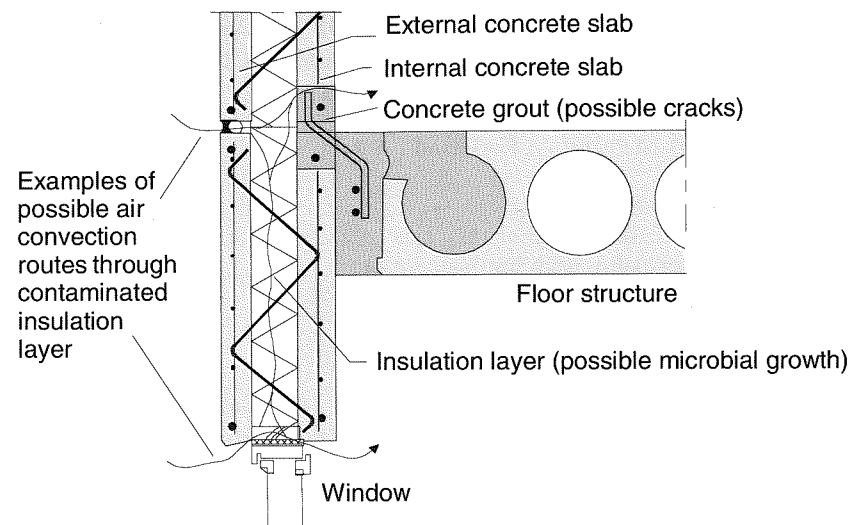Window

Figure 1. Sandwich panel structure and examples of possible air convection routes

the buildings consisted of exhaust air fan without any mechanical air supply. The condition of exterior walls was monitored visually before sampling [4].

We took samples from external wall insulation and cultured mesophilic fungi on MEA and bacteria on TYG agar [2]. For air sampling (Andersen sampler, MEA and TYG), we chose 19 from original 50 buildings having different degree of microbial contamination in the insulation. Apartments next to studied panels were examined visually and with surface moisture probe to avoid interior biocontamination sources. Before sampling, we advised the inhabitants to avoid activities [5] that may disperse spores into the air. Sources of error were surveyed with a questionnaire. Level of cleanliness and amount of pot plants were assessed by the surveyor.

Control flats without fungal or actinobacterial growth in the insulation were chosen from each studied building, or if not available, a flat from a similar building of the same age in the same area. Air samples were taken from 88 flats altogether. Each flat was sampled three times if possible in spring 1997 and from late autumn 1997 to spring 1998. At least one sampling per flat was during the snow-cover as recommended for subarctic areas [6]. Control samples were taken outdoors for each sampling day and area but on days with continuous rain, on balcony. If temperature dropped below –5 °C or in a case of snowfall, the outdoor counts were set to 0 cfu/m^3 in statistical analyses. Moisture content (g/m^3) of indoor air was calculated from relative humidity (RH) and air temperature by using approximate formula of Nevander and Elmarsson [7]. Fungal colonies were counted after 7-d and bacteria after 10-d incubation and the counts were given in cfu/m^3.

Generalized Linear Mixed Models (GLMM) [8] were used to analyse insulation contamination–other sources–indoor air relations (Table 1). The used model predicts probabilities of studied event (concentrations indoors) to occur for fixed class variables (e.g. snow cover) and covariates (e.g. moisture content of indoor air). Airborne count distribution was assumed to follow Poisson distribution. Analysis was done with Glimmix macro in SAS®. Buildings were considered as random effect, and flats were nested within buildings. Sampling times were

nested within flats. Indoor air fungal counts are strongly dependent on outdoor air [e.g. 9]. In view of that, we modelled also modified fungal value (F^m), where *Cladosporium, Fusidium, Penicillium,* sterile mycelia, and basidiomycetes were excluded from total fungi (F^t).

Table 1. Modeling table: tested determining variables used in GLMM for indoor air concentrations. A=actinobacteria, B=other bacteria, F^t=fungi total, F^m=modified fungal value, class=fixed class variable, cov=covariate, X=included to the model, Z=insignificant, but included to the model, - =tested, but excluded from the model.

Determining variables		Airborne			
		A	B	F^t	F^m
Insulation microbes	Average of panel margin samples; cov	X	-	Z	X
	Average of all samples ; cov	-	Z	-	-
Other microbial sources	Window ventilation on the sampling day; class (0-1)	-	-	-	X
	Pot plants; class (0-3)	-	-	X	-
	Soil handling previous week; class (0-1)	-	-	-	-
	Pets; class (0-1)	-	-	-	-
	A, B, F^t, and F^m counts outdoors; cov	-	-	X	X
Climatic parameters	Snow cover; class (0-1)	X	X	X	X
	Night frost; class (0-1)	X	X	X	X
	Moisture content of indoor air (g/m^3); cov	X	X	X	X
	RH indoors; cov	-	-	-	
	Temperature indoors/outdoors, cov	-	-	-	
	Mean temperature outdoors; cov	-	-	-	
Building factors	Age of the building; cov	-	-	-	-
	Curving of the sandwich panels; class (1-3)	-	-	-	-
	Deterioration of elastic joints outside; class (1-3)	X	-	-	-

RESULTS

Basic statistics showed slightly higher geometric means of airborne actinobacteria and fungal counts in test flats compared to control flats; other bacteria did not differ (Table 2). Due to changing environmental factors and background sources affecting indoor air spora, simple comparisons of averages would not have given a sufficient explanation, but we considered these factors in modeling.

Table 2. Statistics of measured airborne counts in test and control flats, and outdoor air: number of air samples (N), geometric means (GM), 95% confidence interval (CI), and range.

Sampling		N	Airborne concentrations (cfu/m^3)		Range (cfu/m^3)
			GM	95% CI	
Actinobacteria	Test flats; insul. >100 cfu/g	141	1.5	1.1-2.0	0-45
	Ctrl flats; insul. ≤100 cfu/g	76	1.0	0.6-1.5	0-21
	Outdoor air	25	0.9	0.5-1.4	0-11
Other bacteria	Flats; insul. >10000 cfu/g	76	346.6	258.2-465.2	19-15144
	Flats; insul. ≤10000 cfu/g	147	324.9	258.5-408.3	2-20407
	Outdoor air	31	51.6	26.5-99.6	0-1694
Fungi	Test flats; insul. >1000 cfu/g	146	58.8	47.5-72.7	2-1784
	Ctrl flats; insul. ≤1000 cfu/g	76	51.2	41.2-63.5	9-488
	Outdoor air	31	79.5	41.5-151.4	0-4158

Actinobacteria indoors were exponentially dependent on the concentration in the insulation layer (Table 1, Figure 2 a). We found that a tenfold increase of counts in the insulation layer increased counts in indoor air 1.2 fold (95% CI 1.09 - 1.32). In addition of the moisture

content of indoor air, combinations of snow and night frost affected indoor actinobacterial counts (Figure 2 b-d). Unexpectedly, deteriorated elastic joints decreased the concentrations indoors: in the flats with very good joints, airborne counts were 4.3 fold compared to those with bad conditioned joints (95% CI 0.3-73.5).

Table 3. Factors affecting actinobacterial counts in indoor air. III type F-test table [8].

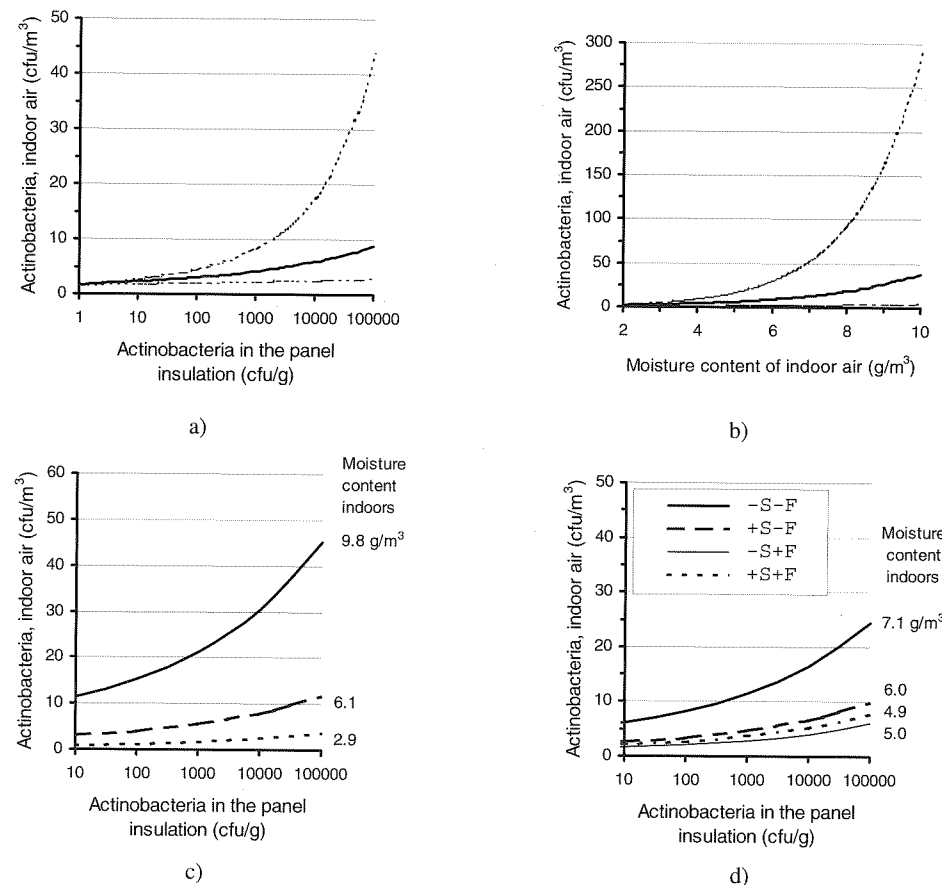| Parameter	ndf	ddf	F	p
Snow cover	1	132.3	0.8	0.3864
Night frost	1	11.5	0.2	0.7036
Snow cover x Night frost	1	136.2	2.8	0.0964°
Condition of elastic joints	3	43.8	3.5	0.0226*
Moisture content of air (g/m^3)	1	67.0	13.1	0.0006***
Actinobacteria in the insulation	1	17.7	11.8	0.0030**

a)

b)

c)

d)

Figure 2. Expected actinobacterial counts of indoor air as a function of a) insulation contamination (broken lines 95 % CI) b) moisture content of indoor air (broken lines 95% CI), c) insulation contamination at different moisture content levels as examples minimum, median and maximum of the used data, and d) insulation contamination at different weather-classes. -S-F=no snow cover, no night frost, +S-F=snow cover, no night frost, -S+F=no snow cover, night frost, +S+F=snow cover and night frost.

Other bacteria found in the insulation layer did not explain airborne counts. In this group, the main factors were indoor air moisture (1 g/m^3 increase increased indoor bacterial counts 1.46 -fold, 95%CI 1.29-1.65, F=36.7, p=0.0001) and winter conditions (snow coverxnight frost).

Fungal counts indoors were explained by several environmental (moisture content; snow coverxnight frost) and source variables (outdoor counts, pot plants), but not insulation contamination. 1 g/m^3 moisture increase multiplied indoor counts 1.34 fold (95%CI 1.18-1.52, F=25.18, p=0.0003). Neither using modified fungal value, we could not show any reasonable relation between insulation and indoor air spora.

DISCUSSION

Microbial sources of indoor air are 1) outdoor air, 2) inhabitant related sources, and 3) microbial growth in building structures. In this study, we evaluated importance of one specific building related source, external wall insulation.

External wall as a biocontamination source has been sparsely studied: insulation layer inside outer walls has been indirectly shown to act as a biocontamination source in brick walls of office buildings [10], in sandwich panels mould growth has been reported on the internal concrete core [11]. In the latter case growth was initiated by condensation of indoor humidity due to serious panel cracks.

Only actinobacterial growth inside the external wall was shown to affect indoor air. Fungal contamination in the insulation was more infrequent than actinobacterial [2] and therefore, the indoor effect might have been difficult to observe. The larger spore size of fungi may prevent penetration through the building envelope [12]. Deteriorated elastic joints increased actino-bacterial contamination in the insulation layer [4] but the same factor decreased counts indoors. This may cope with air convection route inside the external wall, but also with a possible bias of our data: proportion of buildings, both microbiologically contaminated and joints in good repair, was small.

We generally studied only one panel per flat. Air currents from other rooms in the flat, next to unstudied, possibly differently contaminated, panels might have affected the measurements. As further possible sources of error, the lag between insulation studies and indoor air sampling varied from one month to more than one year.

Moisture content of indoor air (g/m^3) was found to be the best environmental explanatory variable in all studied microbial groups indoors. RH is generally used in bioaerosol studies. RH and temperature both indoors and outdoors, besides their interactions, were also found significant, but from these related factors, the moisture content of indoor air fitted best in the model.

Moisture content of indoor air is highly dependent on external events. Usually in properly ventilated apartments the inhabitant activity causes an increase of 2 –3 g water/m^3 to the outdoor air moisture content, but with poor ventilation and with excessive use of water the difference may be much higher. In the northern climate, the outdoor moisture content is in winter below 2 g/m^3 and thus RH indoors decreases below 20% for an extended period.

The main fungal source, outdoor air, is linked to meteorological changes, but not the main bacterial source, inhabitants [13]. Humidity-dependent increase has generally been explained as a result of interior microbial growth [14, 15]. Moreover, the circumstances during the sampling time may also act on measurability of the spores: humidity affects the spore size [e.g. 16, 17] and viability and ability to grow [18]. Changes in humidity may affect microbial growth, spore liberation, and drifting ability in and through the sandwich panel, but also to the measurability via deposition and changes in spore viability.

ACKNOWLEDGEMENTS

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