Project (No. 1.1.1.1/16/A/192)

Development, optimisation and sustainability evaluation of smart solutions for nearly zero energy buildings in real climate conditions

Project activity 4.1.

"The determination of material properties under laboratory conditions"

Tests reports of the properties of 6 materials

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Analyses of microbial pollution in some constructions of test buildings

In order to guarantee confortable microclimate for inhabitants and sustainability of building structures thus providing maximum service life of buildings, it is necessary to be sure that the risk of mould fungi growth is prevented. The presence of fungi in the buildings depends on a lot of factors, for example, such as microbial content of outdoor air and building maintenance (e.g., ventilation systems, temperature, relative humidity (RH)). Mostly the cause of excessive moisture that is the most important factor for mould development, in the buildings there can be initial moisture content of used materials, construction shortcomings as well as improper maintenance of the buildings.

The aim of the present research was to study the effect of different building envelope materials on development of fungal pollution in ventilated loft which is made from timber-frame construction with blowing birch wool fibre insulation.

Materials and methods

The collection of the samples in lofts of test stands

The samples were taken from 3 test stands, as different initial moisture levels were observed in these buildings (Fig. 1, 2) [1]:

1) LOG stand (logs with the internal stone wool insulation and wooden planks as interior finish),
2) EXP stand (experimental ceramic blocks filled with insulation granules),
3) AER stand (aerated concrete blocks with the external elastic stone wool insulation).

In each stand, there were taken 2 groups of samples:

1) wool fibre insulation – four samples in different location (e. g., top, bottom, with and without visible mould infestation) (Fig. 3);
2) surface samples from plywood in the wall construction:
   - samples from the surface with visible mould infestation in at least four replications,
   - samples from the surface without visible mould infestation (as control) in at least four replications.

So, in total, there were taken **6 groups of samples** that were collected in 2017/18.

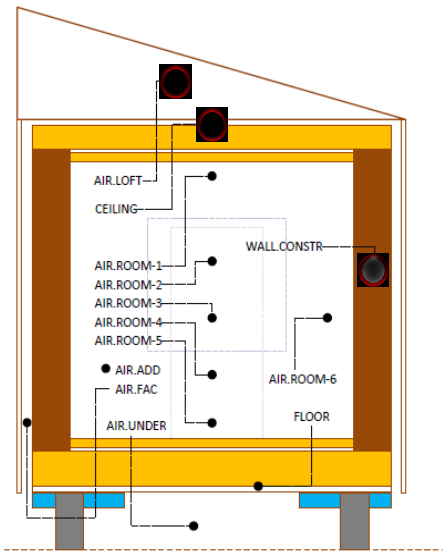

Fig. 1. *The location of the sensors of temperature and relative humidity (T/H) in a test building. The sensors, which data was used in current research, are marked by red circles.*

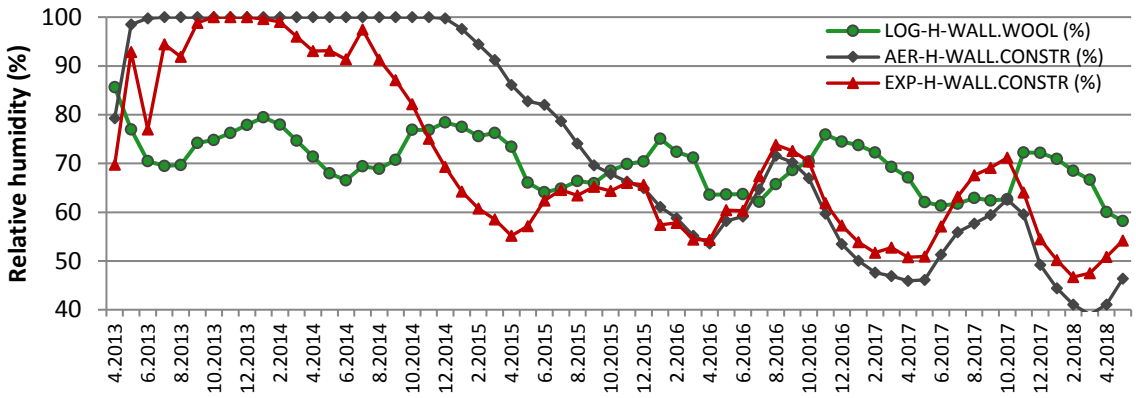

Fig. 2. *Relative humidity in the wall constructions of test stands. The data from sensors WALL CONSTR.*

Microbiological analyses

In order to prepare suspension for examination, 1.0 g of insulation material (wool fibre) was homogenized in 100 ml of sterile distilled water. The surface samples were obtained using a swab method. In order to prepare one sample, one moistened cotton swab was used to wipe 10 cm^2 of the wall surface. These swabs were placed in vials containing 1 ml of sterile distilled water.

One hundred µl of obtained suspensions (from both type of the samples – insulation material and surface of plywood) was plated on Petri plates with 2% Malt Extract Agar (MEA) and Dichloran 18% Glycerol Agar (DG18) in at least four replications for each medium. DG18 Agar was used to isolate and identify xerophilic fungi (*Penicillium*, *Aspargillus*, *Eurotium*), while MEA allowed to develop mesophilic and hydrophilic moulds. If it was necessary the solutions of the samples were additionally diluted from 10^{-1} to 10^{-4}. The plates with the samples were incubated at 20 – 23 °C for 10 – 28 days. Filamentous fungi were identified to the genera level using macro- and micromorphological traits. The number of fungal propagules was expressed as colony-forming units (CFU) to g of insulation material or to cm^2 of the surface.

Fig. 3. *The places where the samples of insulation materials were taken (indicated by red arrows).*

Results and discussion

Visual observation of the loft spaces showed that fungal pollution was more developed on the plywood constructions of the walls in AER stand, while in EXP and LOG stands mould growth was less pronounced and the loft spaces of these stands looked quite similar (Fig. 4). The south side walls of all stands were the cleanest. In AER and EXP stands, the surface insulation material – blowing birch wool fibre – under the plywood cover was coated with mould, but in LOG stand wool fibre looked clean.

The detailed information about the results of the current microbiological analysis is summarized in Tab. 1, 2 and Fig. 5 – 10.

Unfortunately, the data from two sensors of temperature and RH, which were located directly on insulation material (CEILING) and in the middle of the loft space (AIR.LOFT), was incomplete (Fig. 1, Fig. 11, 12). However, data of the sensors gave additional information which helped to explain the obtained results. The data showed that RH level was high not only in AER and EXP stands with initial higher RH, bet also in LOG stand with significant lower RH in the building (Fig. 2) [1, 2]. Therefore, the results revealed that apparently provided ventilation was insufficient in the examined loft spaces.

The results of microbial analyses in the loft space represent moisture regime in the whole test building (Fig. 2). Although, the humidity level allowed to develop not only xerophilic, but also mesophilic and hydrophilic fungi in AER and EXP stands, however, distribution (visual assessment) and concentration of the latter were noticeably higher on the walls of AER stand. According to the humidity data from the sensor which was situated in the middle of the loft space, in AER and EXP stands the humidity patterns were very similar. It endorsed to conclude that such humidity data did not represent moisture regime on the surface of this building structures.

Although, visual assessment of the walls in EXP and LOG stands give quite similar rating, however, microbial analyses revealed what fungal concentration in LOG stand was noticeably lower and humidity level did not allow to develop hydrophilic fungi.

Microbial analyses of insulation material confirmed visual assessment of wood fibres. In AER and EXP stands, wood fibres covered with mould contained high concentration of several hydrophilic fungi (*Chaetomium*, *Geomyces*, *Trichoderma*). At the same time in LOG stand, visually clean fibres contained typical xerophilic fungi (*Aspargillus*, *Penicillium*). It allowed to confirm the opinion that only visual assessment is insufficient to make valuation of fungal pollution. The data of RH from CEILING sensors in AER and LOG stands helped to explain obtained results. During the two warm seasons (2015, 2016) in AER stand the humidity level was significantly higher than in LOG stand and it admitted intensive growth of mould.

The researches related to the assessment of potential fungal pollution development will be continued in the different building structures. It can help to find the best solutions for various materials of building envelope in the current climate conditions.

Fig. 4. *Visual assessment of loft space in test stands.*

Tab. 1. *Concentration (CFU g^{-1}) of culturable fungi in the samples of blowing birch wool fibre insulation in the lofts of the test stands (data are shown as mean values ± standard error).*

Fungi \ *Location of the samples*		**LOG stand -** samples are taken from			
		1. in the middle of the bottom part	2. in the middle of the top part	3. the South side of the bottom part	4. the South side of the top part
		CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
Xerophilic (RH< 80%)	*Aspargillus*	17 189 ± 938	6 250 ± 1 531	18 750 000 ± 3 608 439	937 500 ± 80 687
	Penicillium	37 185 ± 2 065	1 875 ± 361	709 375 000 ± 29 919 597	12 593 750 ± 1 042 552
Mesophilic (RH=80-90%)	*Cladosporium*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Monocillium	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	others*	1 250 ± 884	0 ± 0	0 ± 0	0 ± 0
Hydrophilic (RH>90%)	*Chaetomium*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Geomyces	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Trichoderma	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Total	**55 623 ± 3 886**	**8 125 ± 1 892**	**728 125 000 ± 33 528 036**	**13 531 250 ± 1 123 239**

Fungi \ *Location of the samples*		**EXP stand -** samples are taken from			
		1. the bottom	2. the bottom	3. the top with mould	4. the top with mould
		CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
Xerophilic (RH< 80%)	*Aspargillus*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Penicillium	32 500 000 ± 7 500 000	21 875 000 ± 5 983 919	20 312 500 ± 2 991 960	65 000 000 ± 7 722 397
Mesophilic (RH=80-90%)	*Cladosporium*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Monocillium	22 500 000 ± 4 677 072	134 375 000 ± 39 978 836	0 ± 0	0 ± 0
	others*	0 ± 0	9 375 ± 5 984	0 ± 0	0 ± 0
Hydrophilic (RH>90%)	*Chaetomium*	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Geomyces	62 500 000 ± 3 952 847	412 500 000 ± 141 789 163	0 ± 0	11 562 500 ± 1 562 500
	Trichoderma	0 ± 0	0 ± 0	17 187 500 ± 2 991 960	1 406 250 ± 393 221
	Total	**117 500 000 ± 16 129 919**	**568 759 375 ± 187 757 902**	**37 500 000 ± 5 983 919**	**77 968 750 ± 9 678 118**

continuation of the table on the next page

Fungi \ *Location of the samples*		**AER stand -** samples are taken from											
		1. the South side of the bottom			2. the South side of the top			3. sample - the top with mould			4. sample - the bottom with mould		
		CONCENTRATION			CONCENTRATION			CONCENTRATION			CONCENTRATION		
Xerophilic (RH< 80%)	*Aspargillus*	18 750 000	±	1 250 000	0	±	0	0	±	0	192 500 000	±	54 950 262
	Penicillium	4 500 000	±	1 089 725	0	±	0	0	±	0	15 000 000	±	5 229 125
Mesophilic (RH=80-90%)	*Cladosporium*	0	±	0	0	±	0	0	±	0	0	±	0
	Monocillium	750 000	±	306 186	0	±	0	0	±	0	190 000 000	±	54 914 707
	others*	357 500	±	92 669	0	±	0	0	±	0	0	±	0
Hydrophilic (RH>90%)	*Chaetomium*	0	±	0	0	±	0	0	±	0	7 500 000	±	3 423 266
	Geomyces	4 500 000	±	750 000	62 000 000	±	18 139 003	475 000 000	±	107 529 066	7 500 000	±	5 590 170
	Trichoderma	0	±	0	3 625 000	±	1 091 516	75 000 000	±	30 618 622	0	±	0
	Total	**28 857 500**	**±**	**3 488 580**	**65 625 000**	**±**	**19 230 519**	**550 000 000**	**±**	**138 147 688**	**412 500 000**	**±**	**124 107 52**

*fungi identified only once or twice, such as *Alternaria, Chrysonolia, Geotrychum, Gonatobotrys, Lecythophora, Menispora, Pestalotia, Tretovularia* etc.

Tab. 2. *Density (CFU cm^{-2}) of culturable fungi detected in the surface samples of the walls in lofts of the test stands (data are shown as mean values ± standard error).*

Fungi / Location of the samples		The samples from the visually clean surfaces (control)		
		LOG	EXP	AER
		DENSITY	DENSITY	DENSITY
Xerophilic (RH< 80%)	*Aspargillus*	0.06 ± 0.06	0.44 ± 0.26	8.56 ± 2.17
	Penicillium	0.31 ± 0.24	2.38 ± 1.36	10.81 ± 5.10
Mesophilic (RH=80-90%)	*Cladosporium*	14.56 ± 7.01	28.81 ± 14.35	75.31 ± 33.89
	Monocillium	0.06 ± 0.06	0.19 ± 0.19	0.50 ± 0.35
	yeasts	0.38 ± 0.22	0.44 ± 0.29	0.00 ± 0.00
	others	0.25 ± 0.10	1.38 ± 0.63	0.38 ± 0.22
Hydrophilic (RH>90%)	*Aureobasidium*	0.00 ± 0.00	2.19 ± 1.94	0.00 ± 0.00
	Chaetomium	0.00 ± 0.00	0.44 ± 0.19	1.19 ± 0.61
	Geomyces	0.00 ± 0.00	0.56 ± 0.16	5.25 ± 1.44
	Trichoderma	0.00 ± 0.00	0.38 ± 0.24	0.31 ± 0.19
	Total	**15.62 ± 7.69**	**37.21 ± 19.61**	**102.31 ± 43.97**

Fungi / Location of the samples		The samples from the surfaces covered with mould		
		LOG	EXP	AER
		DENSITY	DENSITY	DENSITY
Xerophilic (RH< 80%)	*Aspargillus*	0.00 ± 0.00	0.00 ± 0.00	0.75 ± 0.43
	Penicillium	0.00 ± 0.00	0.00 ± 0.00	1.44 ± 0.95
Mesophilic (RH=80-90%)	*Cladosporium*	31 625.36 ± 13 392.13	44 250.12 ± 10 141.70	93 018.75 ± 49 927.82
	yeasts	170.50 ± 43.86	135.94 ± 80.22	20.19 ± 19.20
	Total	**31 795.86 ± 13 435.99**	**44 386.06 ± 10 221.92**	**93 041.13 ± 49 948.40**

* fungi identified only once or twice, such as *Geotrychum, Gonytrichum, Lecythophora, Menispora, Tretovularia* etc.

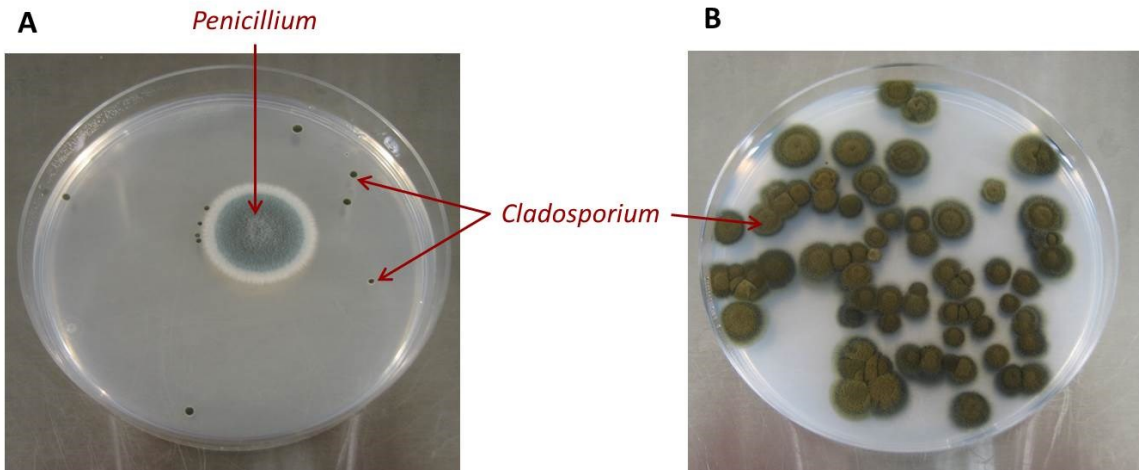

Fig. 5. *Some typical samples from the plywood walls in the loft of LOG stand:*
A – from surfaces without visible mould infestation;
B – from surfaces with visible mould infestation
(100 µl of undiluted suspension on *Petri plates).*

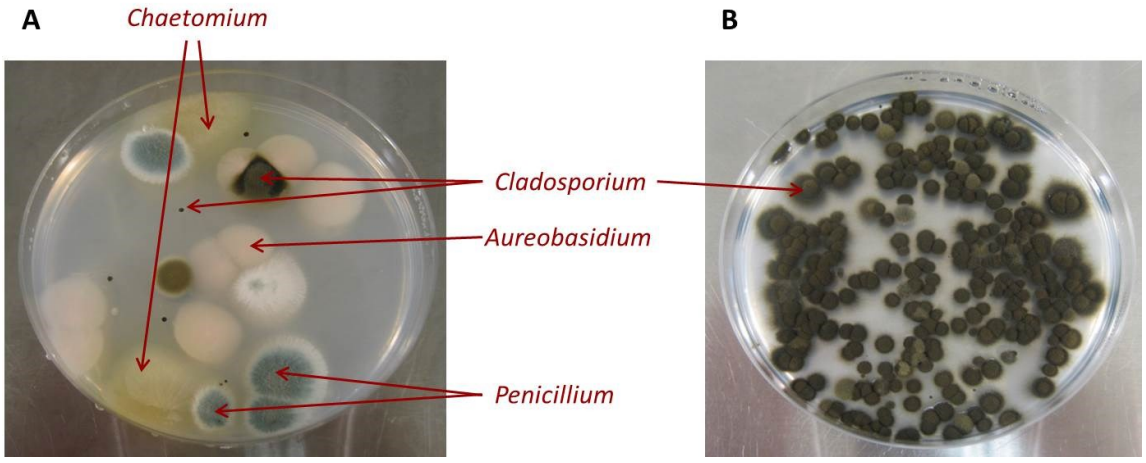

Fig. 6. *Some typical samples from the surface of the plywood walls in the loft of EXP stand: A – from the surfaces without visible mould (100 µl of undiluted suspension on Petri plate); B – from surfaces with visible mould infestation (100 µl of 10^{-2} diluted suspension on Petri plate).*

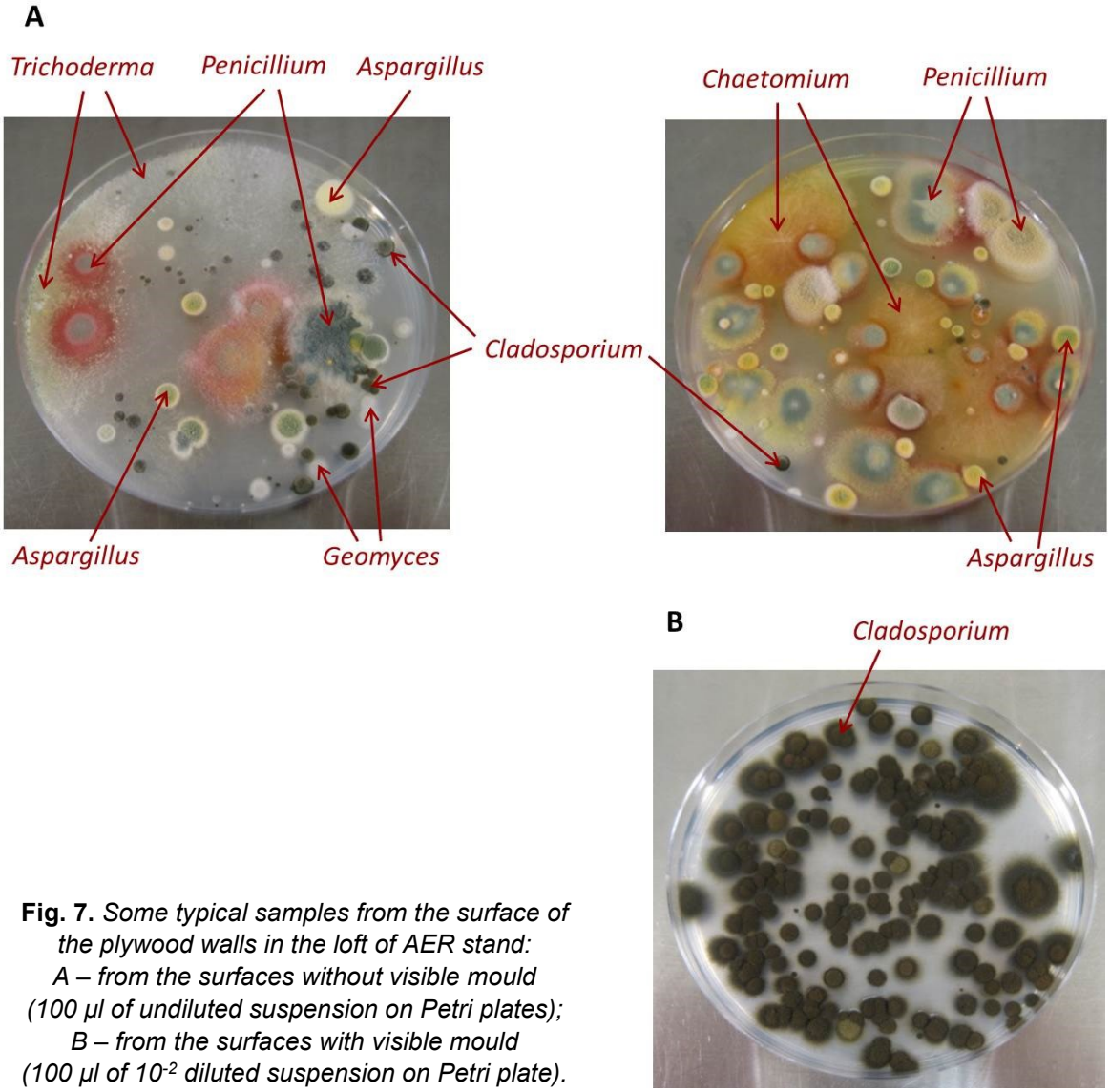

Fig. 7. *Some typical samples from the surface of the plywood walls in the loft of AER stand: A – from the surfaces without visible mould (100 µl of undiluted suspension on Petri plates); B – from the surfaces with visible mould (100 µl of 10^{-2} diluted suspension on Petri plate).*

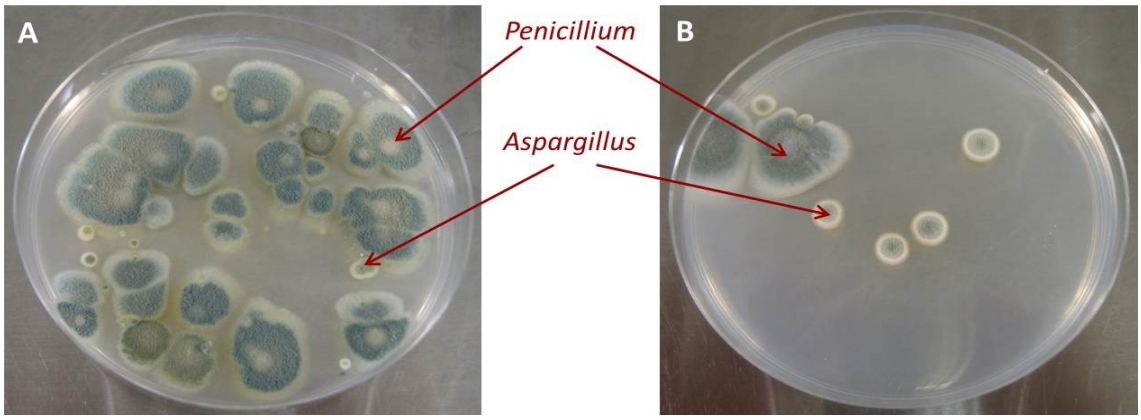

Fig. 8. *Some typical samples of the wool fibre insulation in the loft of LOG stand: A, B – 100 µl of undiluted suspension on Petri plates.*

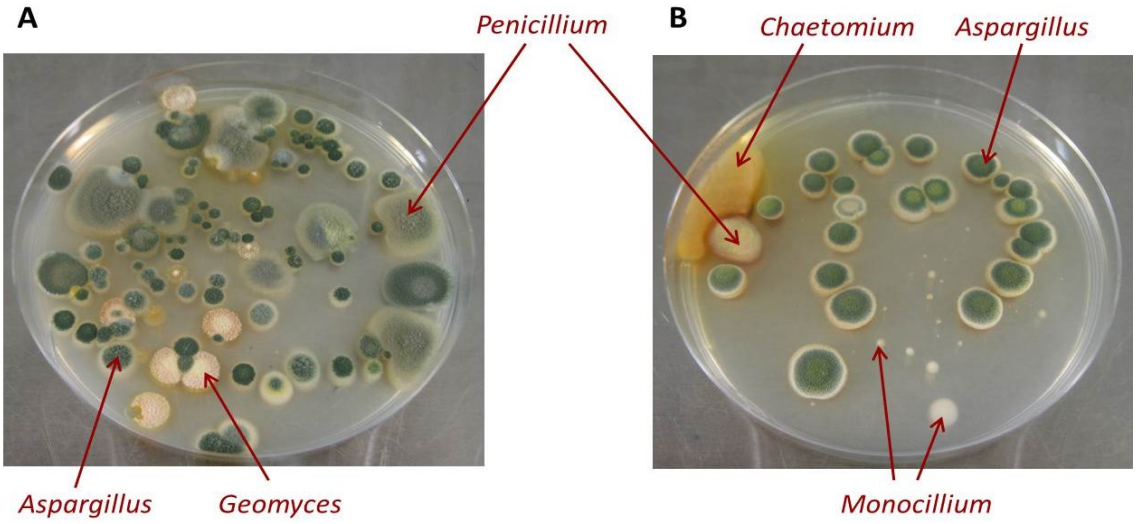

Fig. 9. *Some typical samples of the wool fibre insulation in the loft of EXP stand:*
A – 100 µl of 10^{-2} diluted suspension on Petri plate;
B – 100 µl of 10^{-3} diluted suspension on Petri plate.

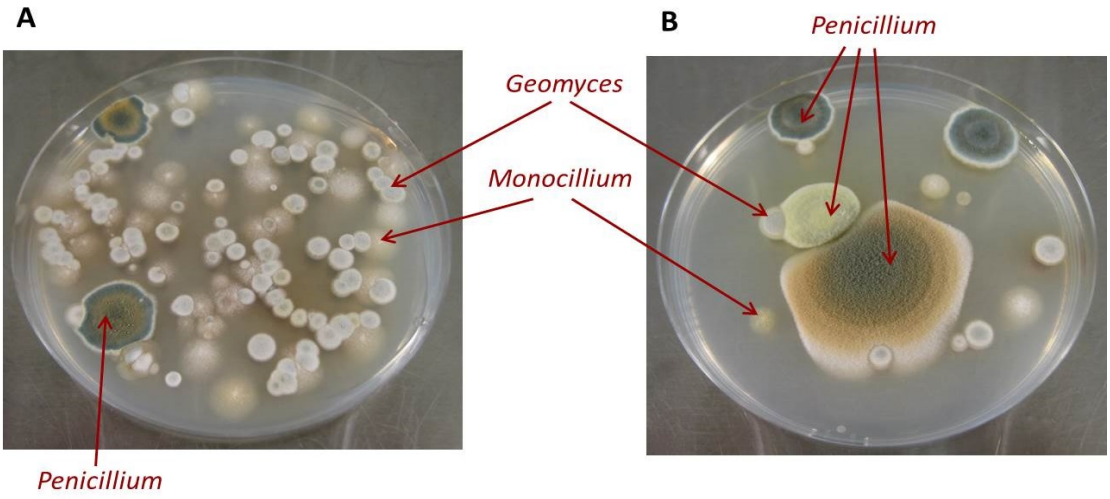

Fig. 10. *Some typical samples of the wool fibre insulation in the loft of AER stand:*
A – 100 µl of 10^{-2} diluted suspension on Petri plate;
B – 100 µl of 10^{-3} diluted suspension on Petri plate.

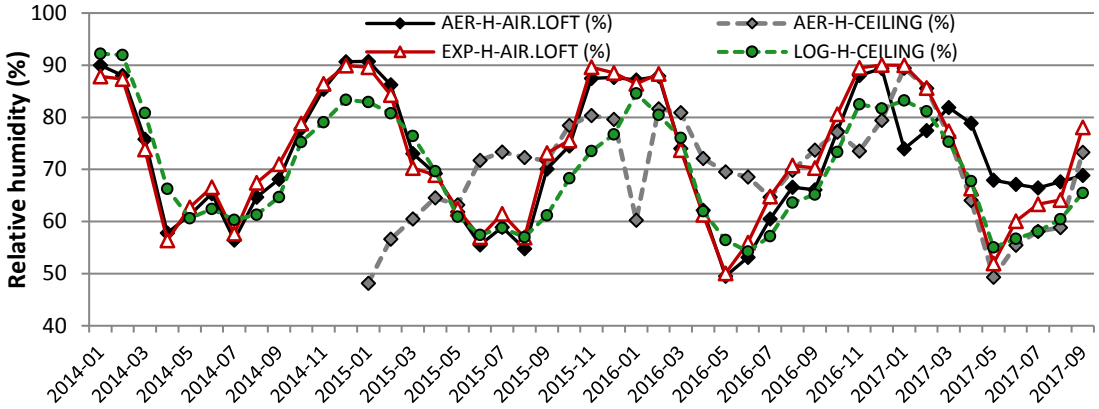

Fig. 11. *Relative humidity of the lofts of AER, EXP and LOG stands. The data from sensors AIR.LOFT, CEILING (Fig. 1).*
Data from sensors LOG-H-AIR.LOFT and EXP-H-CEILING were not available.

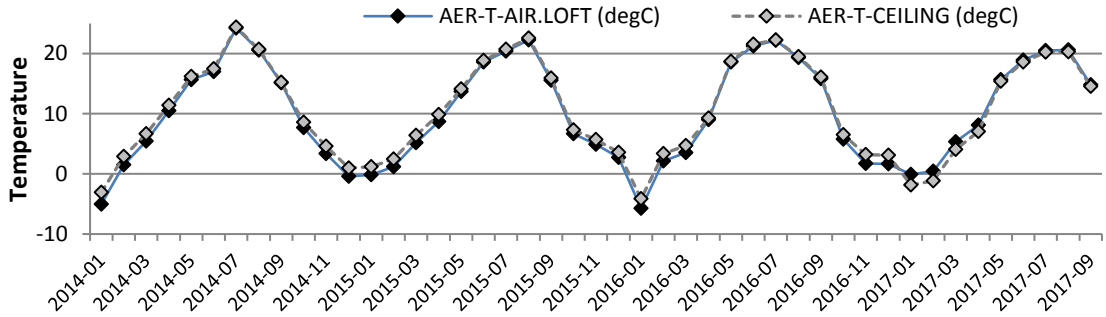

Fig. 12. *Temperature in the lofts of the test stands. As in all stands temperature pattern were very similar, the data is shown only from AER stand.*

References

[1] I. Apine, L. Orola, A. Jakovics. *Effect of building envelope materials on indoor air quality in low energy test houses //* International Journal of Environmental Science and Development. – 2015, Nr. 6, pp. 952 - 957.

[2] A. Jakovics, S. Gendelis, J. Ratnieks, S. Sakipova. *Monitoring and Modelling of Energy Efficiency for Low Energy Testing Houses in Latvian Climate Conditions //* International Journal of Energy. – 2014, Nr. 8, pp. 76 - 83.