Robust solutions of design of internal insulation in historic buildings in regards to hygrothermal performance

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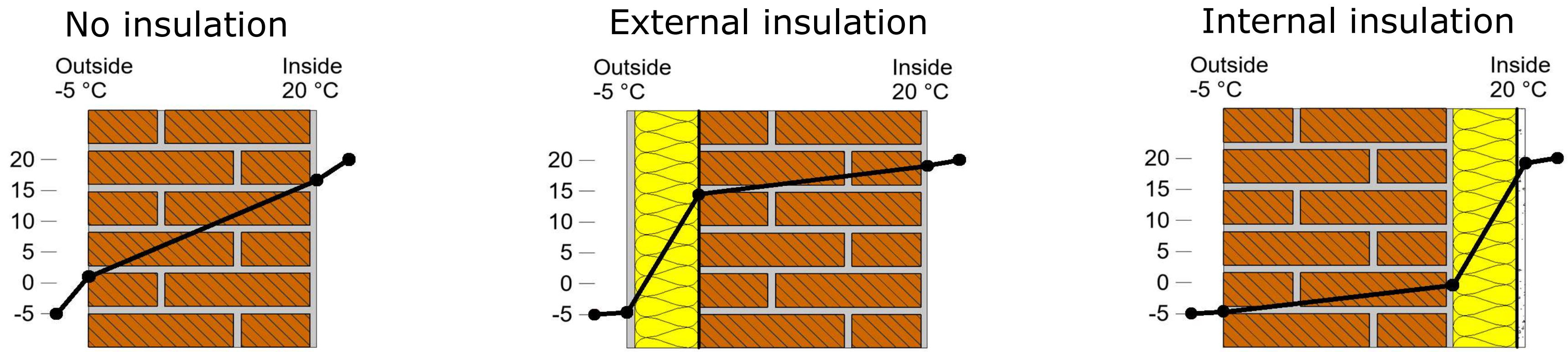
Background and relevance

- In Europe a large share of the building stock was constructed prior to 1945, before we had regulations regarding energy performance.
- A desire to reduce energy consumption and greenhouse gas emissions, and improved indoor thermal comfort



State-of-the-art: Internal insulation

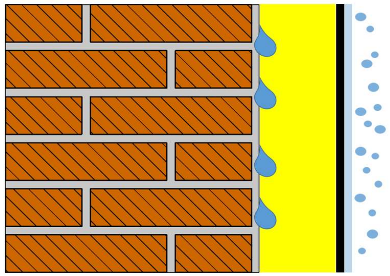
- Applied in buildings where exterior will not be possible
- Reduces heat flow to the existing wall
- Reduces drying potential of the existing wall.
- Does not keep the existing wall warm and protect it against the outdoor climatic conditions.
- Will not revolve thermal bridges



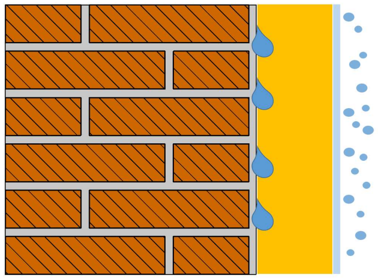
State-of-the-art: Types of internal insulation

Diffusion-tight

Insulation mat with vapour barrier

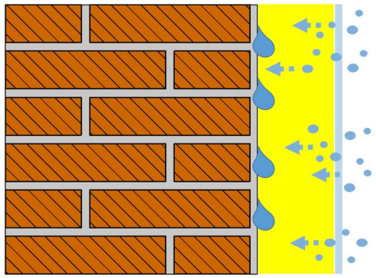


Rigid foam insulation boards with/without barrier



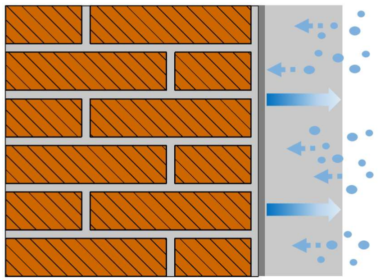
Diffusion-open

E.g. mineral wool or mat of various organic fibres, without vapour barrier



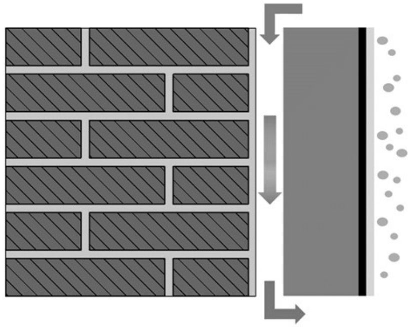
Diffusion-open & **capillary active**

E.g. Calcium silicate or autoclaved aerated concrete



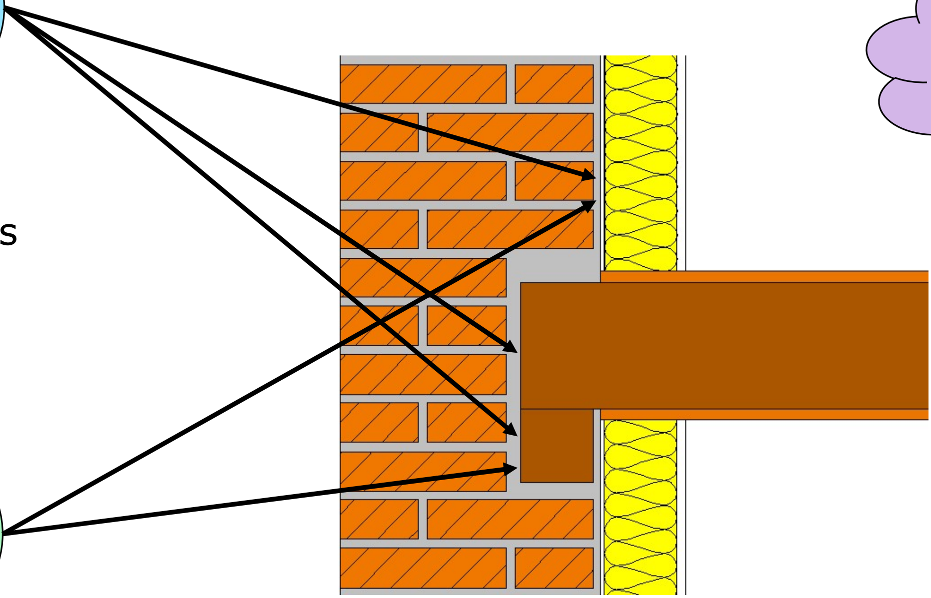
Diffusion-tight with active dehumidification

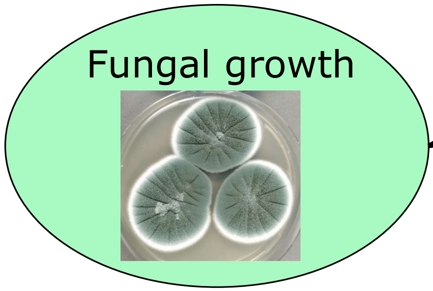
Saint-Gobain Isover RetroWall



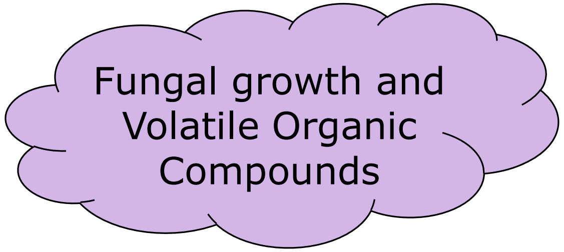
Tre hypotheses

- Insulation systems
- Additional measures





- System manufactures claim: that high pH adhesive mortar prevent fungal growth



- Traditional internal insulation: people got sick in case of fungal growth.
- Will this occur with fully adhered insulation systems?
- Is fungal decontamination prior to installation important?

Hygrothermal performance: diffusion-open, capillary active, and diffusion-tight systems | High moisture levels, fungal growth, pH value and nutrients | Fungal growth and the indoor environment

Methods: experiment 1

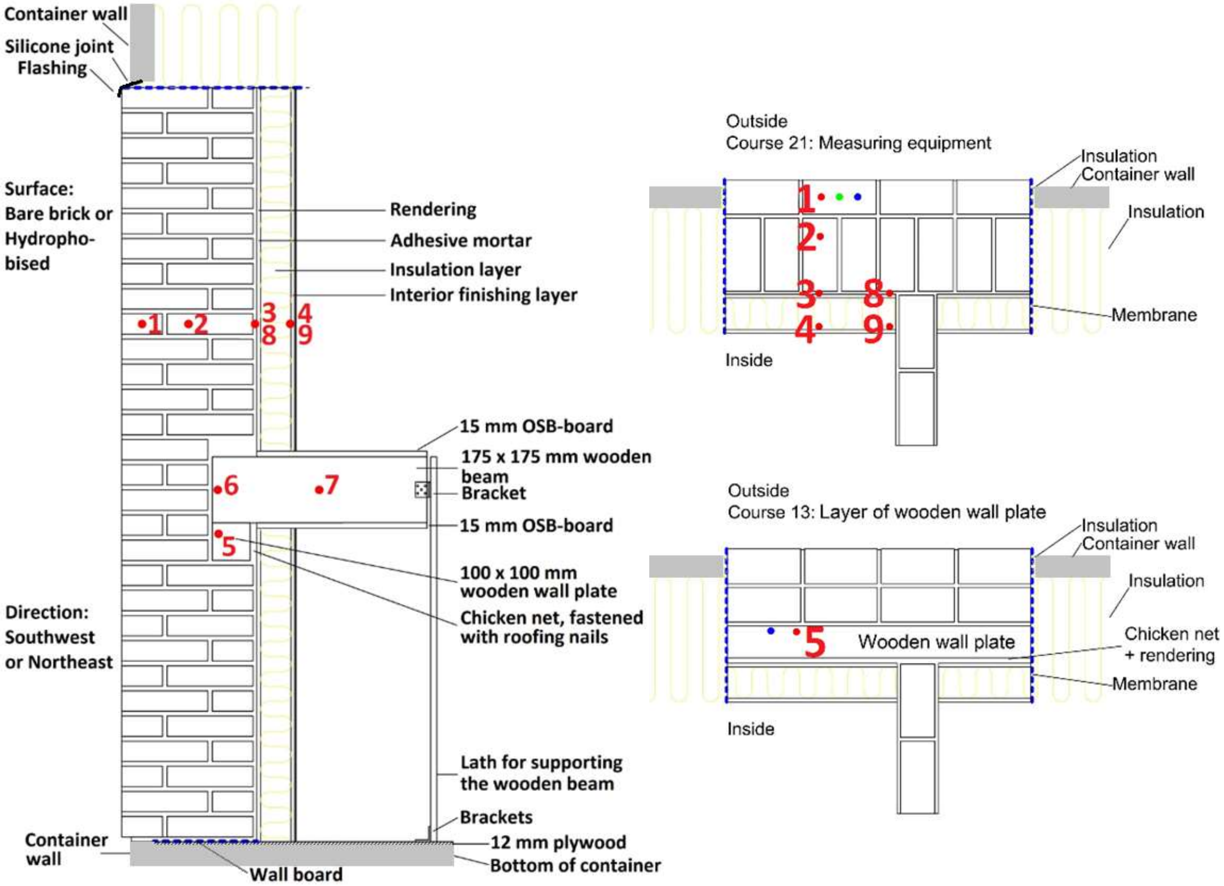
Large scale field experiment

- 2 test containers and 24 test walls (16 facing south-west & 8 facing north-east)
- 1½ brick thick walls (358 mm)
- Constructed with interior partition wall, embedded wooden wall plate and beam end
- 8 insulation systems
- Walls with/without hydrophobisation on the exterior surface

Methods: experiment 1

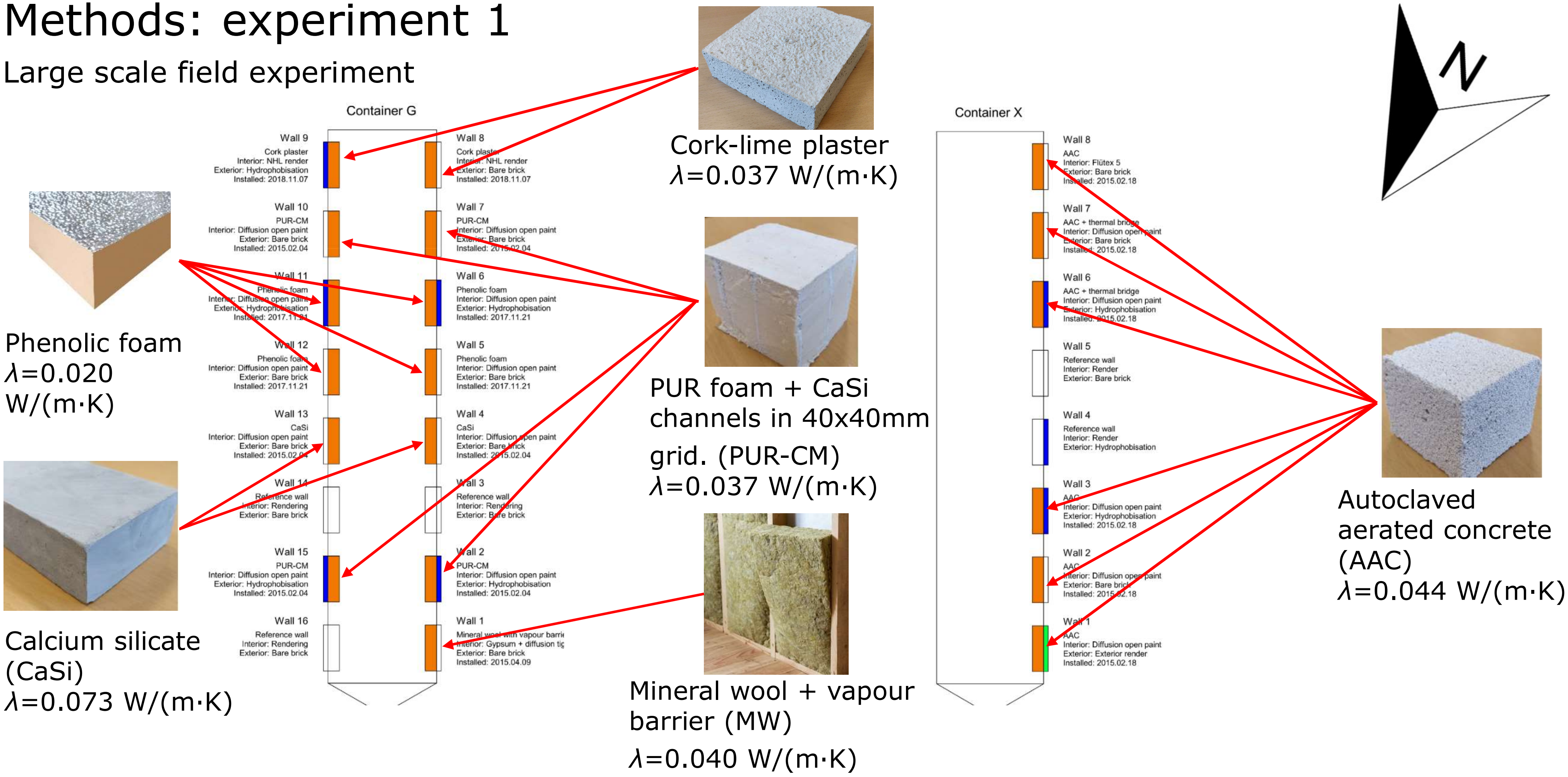
Large scale field experiment

- 9 digital sensors per wall (red dots)
- DC electical resistance in wood and gypsum dowels (blue and green dots)
- Indoor boundary:
  - 20 °C and 60% RH
- No cooling/ dehumidification



Methods: experiment 1

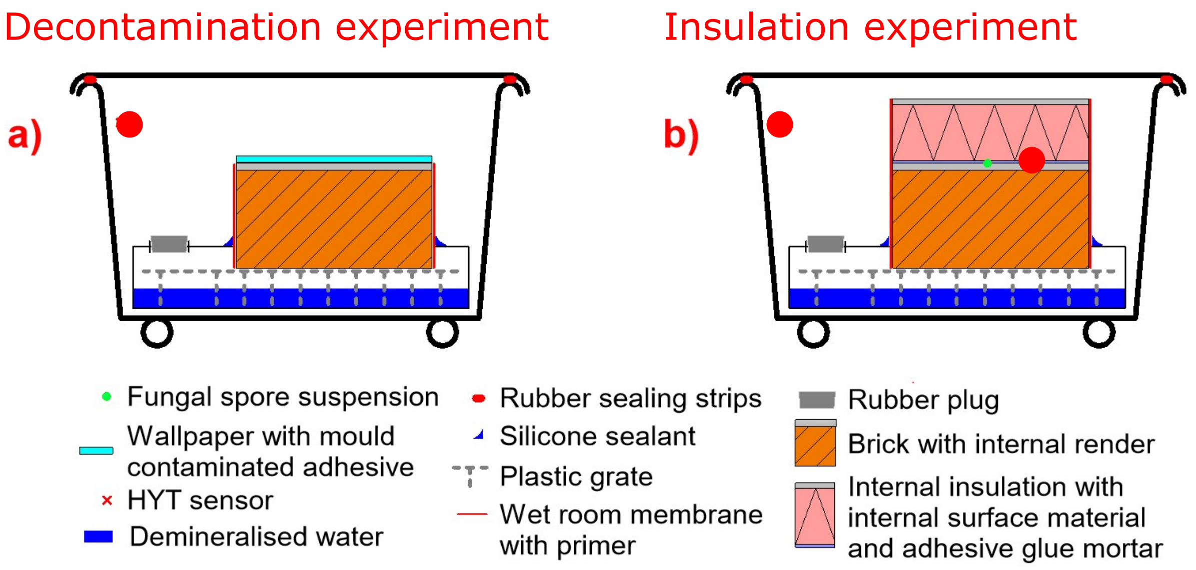
Large scale field experiment



Methods: experiment 2 and 3

Small-scale test walls

- Two consecutive experiments
- 17 test walls
(LxWxH: 350 mm x 350 mm x 180 mm)
- Small box: serves as water reservoir
- Large box: serves as small climate zone
- Aim: to maintain RH > 96% in masonry/ insulation interface
- Digital sensors in wall interface and climate zones (red dots)
- Artificially contaminated with spores from 4 common indoor fungal species
(with different moisture requirements)



Methods: experiment 2

Fungal decontamination experiment

- 12 test walls fitted with woodchip wallpaper, artificially contaminated
- 5 un-inoculated reference walls
- 3 decontamination methods

Hand-power
paint scraper

Mechanical
hammer and chisel

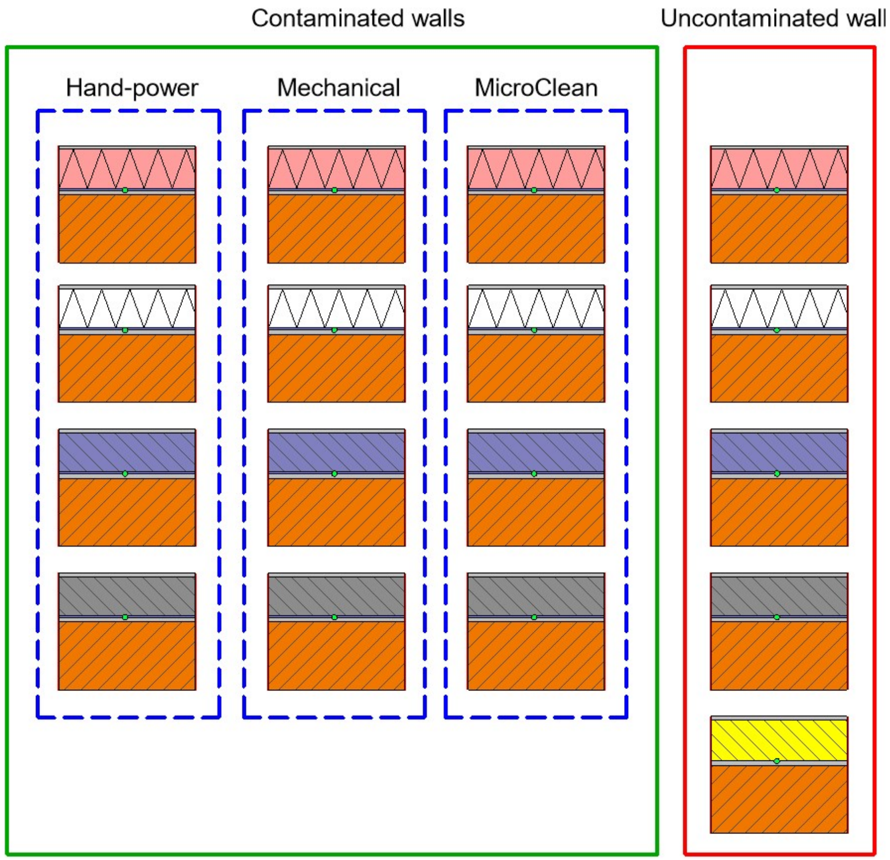
Micro-clean method
(Dry-steam cleaning)

Methods: experiment 3

Internal insulation experiment

- 17 test walls
- 5 insulation systems (Phenolic foam, PUR-CM, AAC, CaSi, and Cork-lime render)

- Spore suspension given in the centre of the test surface (prior to installation of systems)
- Material and fungal samples taken after 6 and 12 months



Methods: Fungal testing (experiment 1, 2 and 3)

Fungal growth testing procedure

- Air samples
  1) 100 L air passed over Petri dishes

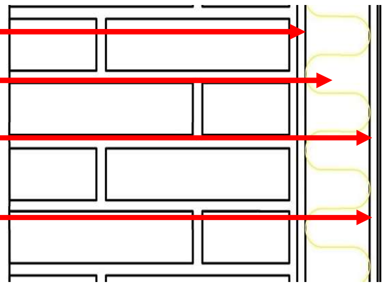
- Core samples
  2) Drilling out core samples
  3) Mycometer surface test
  4) Swab test or Agar contact plate
  5) Material samples (moisture content and pH)
  6) Mycometer bulk material test (later in laboratory)
  7) Mycometer fungal analysis

Methods: Experiment 4

VOC diffusion experiment

- Cup experiment to mimic diffusion of MVOCs produced by fungal growth

- Tests for:
  - adhesive glue mortars
  - insulation materials
  - membranes
  - Renders
  - gypsum board



- 3 VOCs: Acetone, Ethanol, 2-heptanone

- Compared diffusion through the entire systems to convection through a 1 m by 1 cm crack

Results: Hypothesis 1

Hygrothermal performance: diffusion-open, capillary active, and diffusion-tight systems

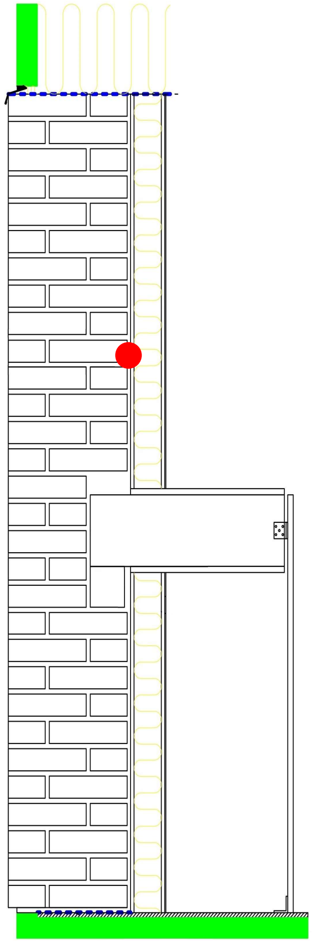
High moisture levels, fungal growth, pH value and nutrients

Fungal growth and the indoor environment

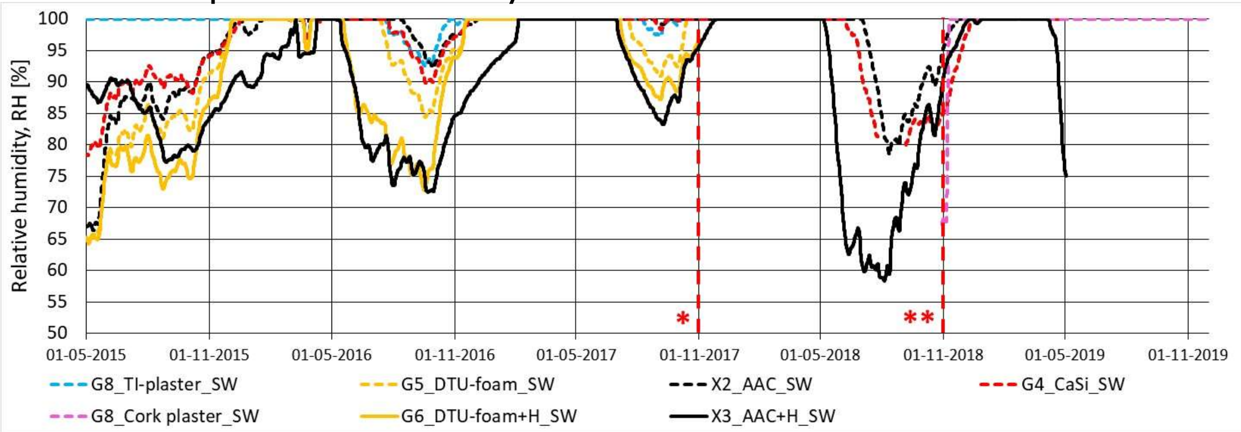
Results

RH in masonry/ insulation interface

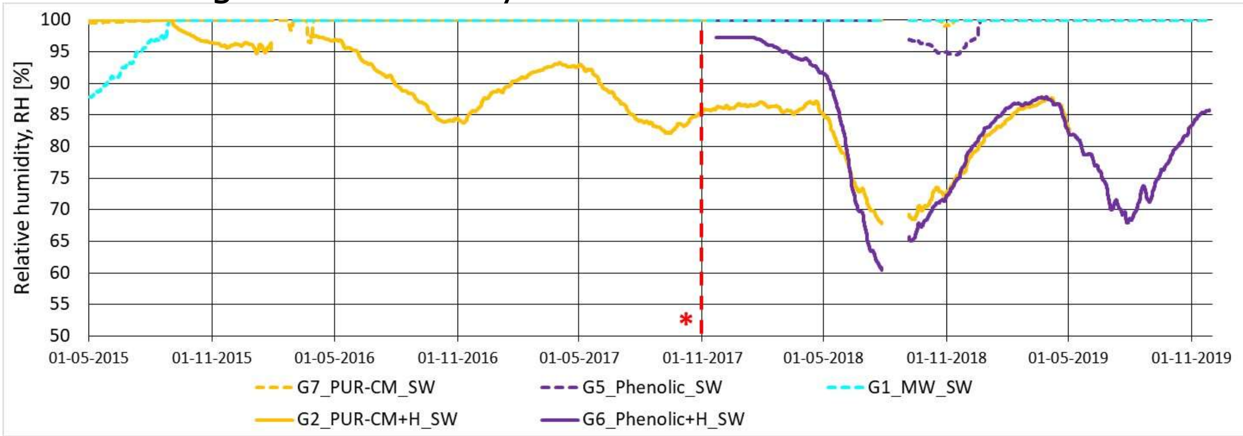
- Unacceptably high RH in walls without hydrophobisation
- Positive effect from hydrophobisation
- Effect from hydrophobisation varied between systems and orientations



Diffusion-open insulation systems



Diffusion-tight insulation systems

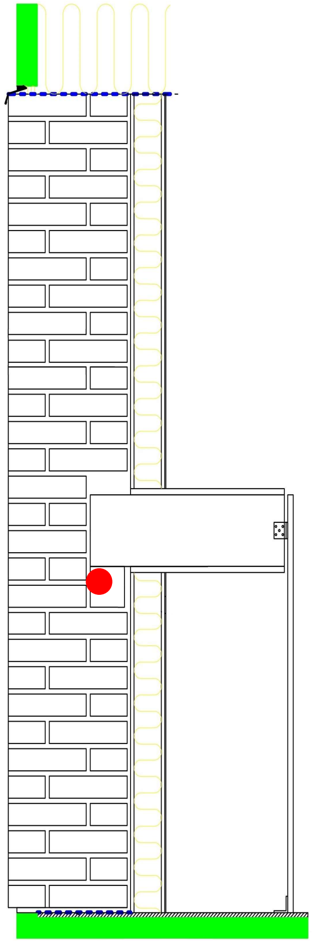


+H: hydrophobisation, *Installation Phenolic, ** Installation Cork-lime

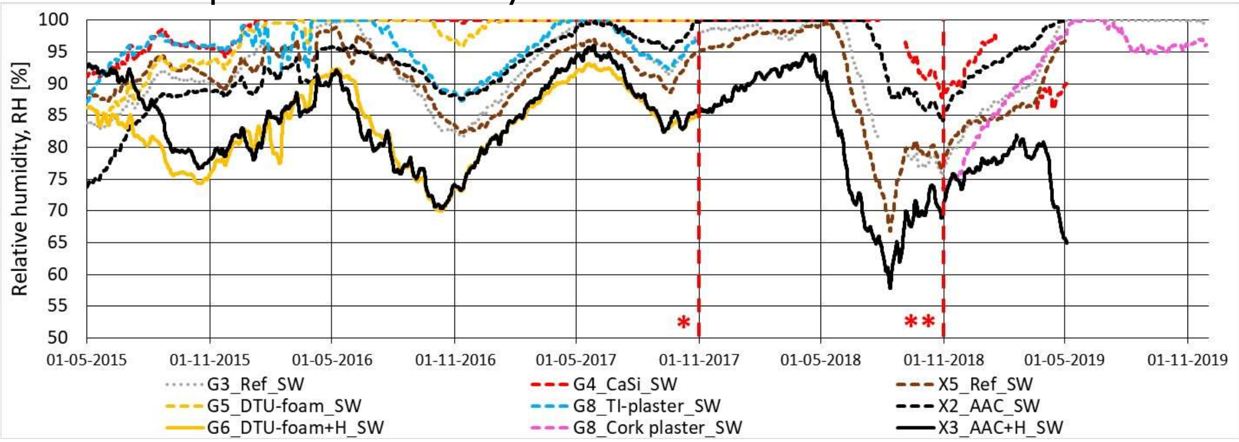
Results

RH in wooden wall plate

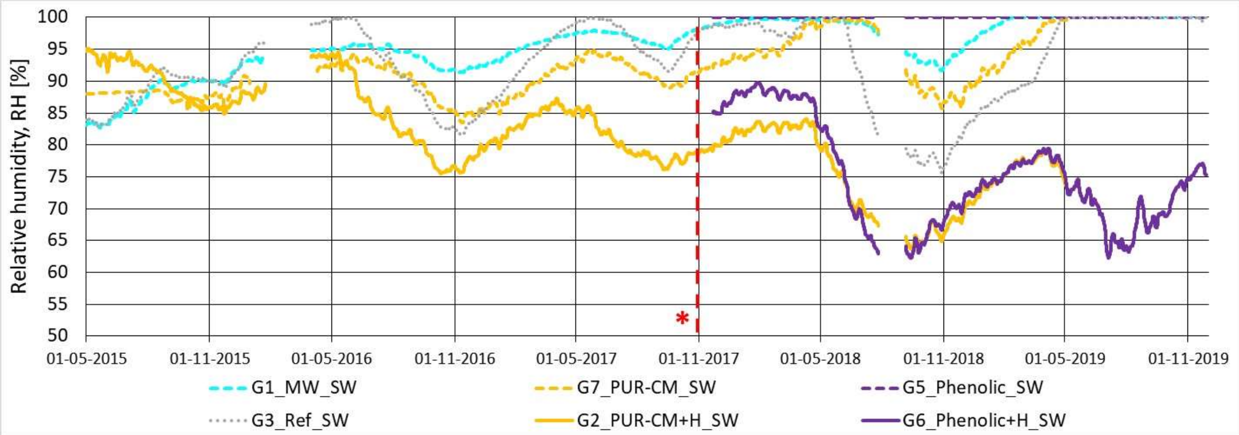
- Potentially critical RH in walls without hydrophobisation
- Positive effect from hydrophobisation
- Less critical moisture levels in diffusion-tight systems
- RH in wall plates more critical than in beam ends



Diffusion-open insulation systems



Diffusion-tight insulation systems



+H: hydrophobisation, *Installation Phenolic, ** Installation Cork-lime

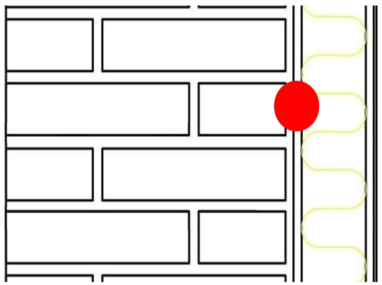
Results: Hypothesis 2

Hygrothermal performance: diffusion-open, capillary active, and diffusion-tight systems | High moisture levels, fungal growth, pH value and nutrients | Fungal growth and the indoor environment

Results

pH test:
Large test walls

- High initial pH (>11) in all systems
- pH declined over time
- High pH was maintained for longer in more diffusion-tight systems
- Low pH (<9.5) in highly diffusion-open systems within 3½ years



*Cork-lime plaster, not adhesive mortar

Wall ID	Fresh lime render	Lime render (Nov. 2018) (after 3½ years)	Lime render (Sep. 2019) (after 4½ years)	Lime render (Dec. 2019)	Fresh adhesive mortar	Adhesive mortars (Nov. 2018) (after 3½ years)	Adhesive mortars (Sep. 2019) (after 4½ years)	Adhesive mortars (Dec. 2019)
G1_MW_SW	12.7	9.2	9.2	10.0				
G3_Reference_SW	12.7	9.2	9.3	9.3				
G14_Reference_NE	12.7		9.2	9.2				
X5_Ref_SW	12.7		9.1					
G4_CaSi_SW	12.7	9.5	9.4		12.7	10.2	9.0	
G13_CaSi_NE	12.7	9.5	9.3		12.7	10.8	9.2	
X1_AAC+R_SW	12.7	9.5	9.5		12.0	9.4	9.2	
X2_AAC_SW	12.7	9.4	9.4		12.0	9.7	9.2	
X3_AAC+H_SW	12.7	9.4	9.1		12.0	9.5	9.5	
X6_AAC+H+TB_SW	12.7		9.3		12.0		9.0	
G8_Cork Plaster_SW	12.7			11.7	12.7*			12.0*
G9_Cork Plaster+H_NE	12.7			10.9	12.7*			12.1*
G2_PUR-CM+H_SW	12.7	12.6	12.0		12.0	12.6	12.5	
G7_PUR-CM_SW	12.7	12.7	12.1		12.0	12.5	12.2	
G10_PUR-CM_NE	12.7	9.7	12.4		12.0	12.6	12.2	
G15_PUR-CM+H_NE	12.7	12.8	12.5		12.0	12.6	12.3	
G5_Phenolic_SW	12.7			12.6	12.4			12.5
G6_Phenolic+H_SW	12.7			12.7	12.4			12.6
G11_Phenolic+H_NE	12.7			12.7	12.4			12.6
G12_Phenolic_NE	12.7			11.9	12.4			12.5

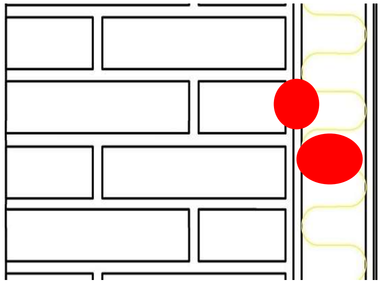
Results

BDL: Below Detection Level

Fungal tests:
Large test walls/high pH

- Mycometer tests:
  Fungal biomass below normal background level
- Swab tests:
  No colony forming spores found in samples taken in PUR-CM and Phenolic foam walls

- No fungal growth detected in systems with high pH



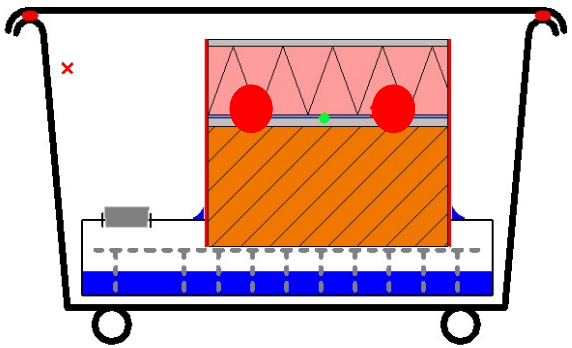
Test round	Wall ID	Surface test		Bulk material test	
		A	B	Outer A	Outer B
1 (Nov. 2018)	G2_PUR-CM+H_SW	BDL	BDL	77	32
	G7_PUR-CM_SW	BDL	BDL	12	27
	G10_PUR-CM_NE	BDL	BDL	4	89
	G15_PUR-CM+H_NE	BDL	BDL	BDL	1
	G5_Phenolic_SW	BDL	BDL	BDL	BDL
	G6_Phenolic+H_SW	BDL	BDL	BDL	BDL
	G11_Phenolic+H_NE	BDL	BDL	BDL	BDL
	G12_Phenolic_NE	BDL	BDL	BDL	BDL
4 (Sep. 2019)	G2_PUR-CM+H_SW	3	3	6	5
	G7_PUR-CM_SW	23	23	9	63
	G10_PUR-CM_NE	12	9	13	1
	G15_PUR-CM+H_NE	8	5	10	18
5 (Dec. 2019)	G5_Phenolic_SW	17	4	1	11
	G6_Phenolic+H_SW	12	12	1	BDL
	G11_Phenolic+H_NE	12	18	BDL	1
	G12_Phenolic_NE	37	6	5	BDL
	G8_Cork Plaster_SW	12	31	35	34
	G9_Cork Plaster+H_SW	30	26	28	26

Hygrothermal performance: diffusion-open, capillary active, and diffusion-tight systems | **High moisture levels, fungal growth, pH value and nutrients** | Fungal growth and the indoor environment

Results

Fungal tests:
Small-scale test walls/high pH

- Mycometer tests: Fungal biomass below normal background level
- Agar contact plate: Fungal spores viable in large numbers
- Most prevailing fungi: *Aspergillus versicolor*



BDL: Below Detection Level

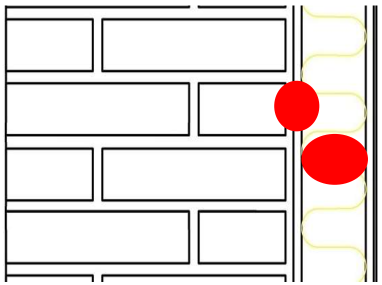
	Mycometer Value (MV)										Colony forming units (CFU)	
	Results after 6 months					Results after 12 months					Total CFU from V8 and DG18	
	Masonry/ insulation interface		Adhesive mortar	Outermos t 10 mm insulation		Masonry/ insulation interface		Adhesive mortar	Outermos t 10 mm insulation		6 months	12 months
	A	B		A	B	A	B		A	B		
PUR-CM Hand-power	46	11	6	10	5	11	15	16	3	2	3	154
Phenolic Hand-power	5	8	6	8	4	11	12	5	1	1	2	1200
AAC Hand-power	7	7	4	4	3	10	8	9	1	1	58	475
CaSi Hand-power	7	12	6	13	38	10	9	10	22	23	0	100
PUR-CM Mechanical	17	5	3	4	3	13	12	BDL	3	0	1	0
Phenolic Mechanical	1	3	8	8	5	34	41	19	2	1	634	611
AAC Mechanical	BDL	0	6	7	3	5	5	2	4	1	7	3
CaSi Mechanical	4	9	5	18	36	7	11	42	30	20	2	28
PUR-CM Microclean	14	14	5	3	4	15	16	30	3	1	2	301
Phenolic Microclean	26	6	4	6	6	9	18	21	36	10	112	1214
AAC Microclean	32	14	19	7	4	8	15	6	3	5	0	4
CaSi Microclean	20	7	6	25	26	3	13	6	36	33	228	8
PUR-CM Un-inoculated	7	7	4	20	2	11	11	2	1	3	75	4
Phenolic Un-inoculated	3	1	2	5	3	18	19	19	1	1	216	359
AAC Un-inoculated	3	2	2	5	3	6	5	4	2	2	5	13
CaSi Un-inoculated	5	5	13	18	38	9	10	9	21	21	5	168
Cork plaster Un-inoculated	19	26		26	27	12	13		19	19	1	3

Hygrothermal performance: diffusion-open, capillary active, and diffusion-tight systems | High moisture levels, fungal growth, pH value and nutrients | Fungal growth and the indoor environment

Results

Fungal tests: Large test walls/low pH

- Below background level biomass in CaSi walls
- High fungal biomass in AAC and MW walls
- Fungal growth in AAC likely due to the presence of organic additives in adhesive mortar (determined by TGA)



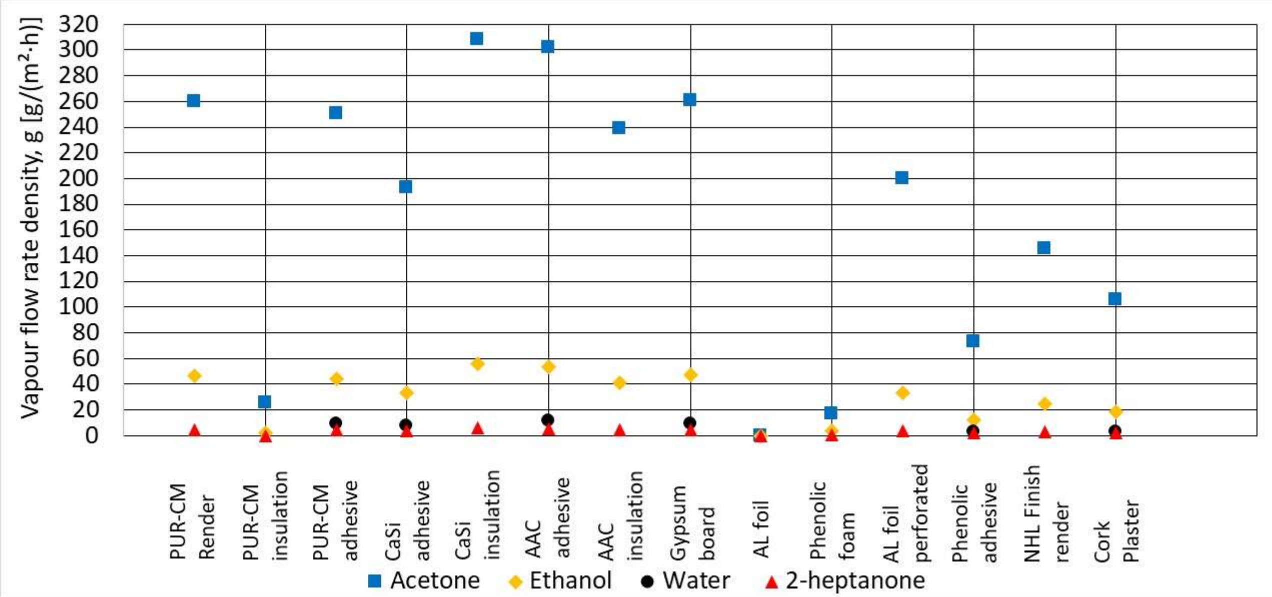
Test round	Insulation system	Surface A	Surface B	Material Outer A	Material Outer B	Material Mid A	Material Mid B	Material Inner A	Material Inner B
1 (Nov. 2018)	G1_MW_SW	21	BDL	469	159				
	G1_MW_SW (Wood stud)	960	788						
	G4_CaSi_SW	BDL	BDL	BDL	BDL				
	G13_CaSi_NE	BDL	BDL	14	10				
	X1_AAC+R_SW	BDL	BDL	162	139	112	112		
	X2_AAC_SW	BDL	41	482	1459	382	390	BDL	7
	X3_AAC+H_SW	26	37	43	32				
2 (Mar. 2019)	X1_AAC+R_SW	157	123	257	230	494	598	7	6
	X2_AAC_SW	141	86	384	254	416	459	6	7
	X3_AAC+H_SW	26	31	209	410	90	69		
3 (Mar. 2019)	X1_AAC+R_SW	227	159	969	1084	134	128	6	7
	X2_AAC_SW	220	196	824	982	119	98	6	6
	X3_AAC+H_SW	120	307	585	712	5	3	5	6
4 (Sep. 2019)	G1_MW_SW	28	13	53	23				
	G1_MW_SW (Wood stud)	35	188						
	G4_CaSi_SW	4	6	9	5				
	G13_CaSi_NE	5	5	4	5				
	X1_AAC+R_SW	42	32	377	423	59	54		
	X2_AAC_SW	140	137	332	461	27	24		
	X3_AAC+H_SW	195	227	450	490	3	24		
	X6_AAC+H+TB_SW (S1)	27	102	45	48	3	2		
	X6_AAC+H+TB_SW (S2)	165	56	224	239	3	3		
	X6_AAC+H+TB_SW (S3)	235	255	451	582	19	10		
5 (Dec. 2019)	G1_MW_SW			195	394				
	G1_MW_SW (Wood stud)	615	162						

Results: Hypothesis 3

Results

VOC diffusion experiment

- VOCs were able to penetrate most examined materials
- Higher vapour flow rate density for more volatile VOCs



Diffusive and convective VOC transfer

- VOC convection was similar to diffusion through highly diffusion-open systems.
- VOC convection was higher than diffusion through more diffusion-tight systems
- More diffusion-tight systems will provide better protection

Vapour diffusion and convection flows through the insulation systems [kg/day]

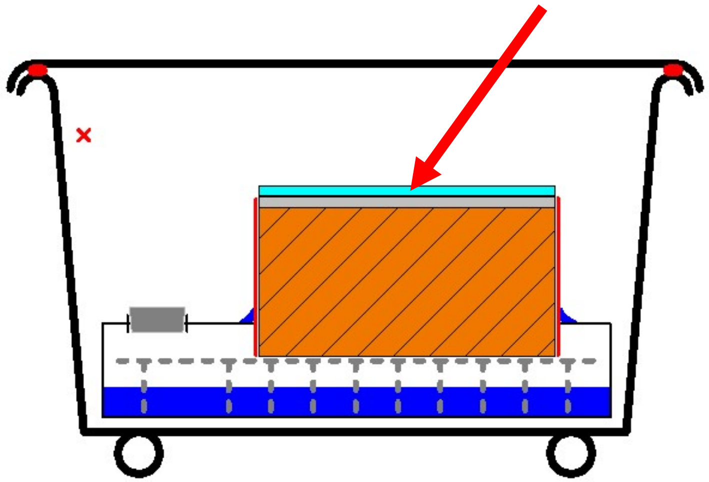
	Acetone	Ethanol	2-heptanone	Water
Convective flow	1.548	0.297	0.018	0.009
CaSi	1.175	0.208	0.022	0.015
AAC	1.175	0.200	0.022	0.016
PUR-CM	0.216	0.013	0.001	0.003
Phenolic	0.0004	0.0002	0.0002	0.0007
Cork Plaster	1.016	0.169	0.019	0.032

Results

Fungal decontamination methods

- Hand-power (paint scraper): insufficient
- Mechanical (hammer & chisel): very effective
- Micro-clean (dry-steam): effective, but risk of under-treating or missing areas

- Choice of method, minor importance
  - ➢ For systems with high pH adhesive mortars



Mycometer Surface Value (MSV)	Hand-power				Mechanical				Micro-clean			
	Wall1	Wall2	Wall3	Wall4	Wall1	Wall2	Wall3	Wall4	Wall1	Wall2	Wall3	Wall4
Sample A	2388	4117	3644	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	69
Sample B	4353	2653	5794	4212	BDL	BDL	BDL	BDL	BDL	BDL	BDL	66

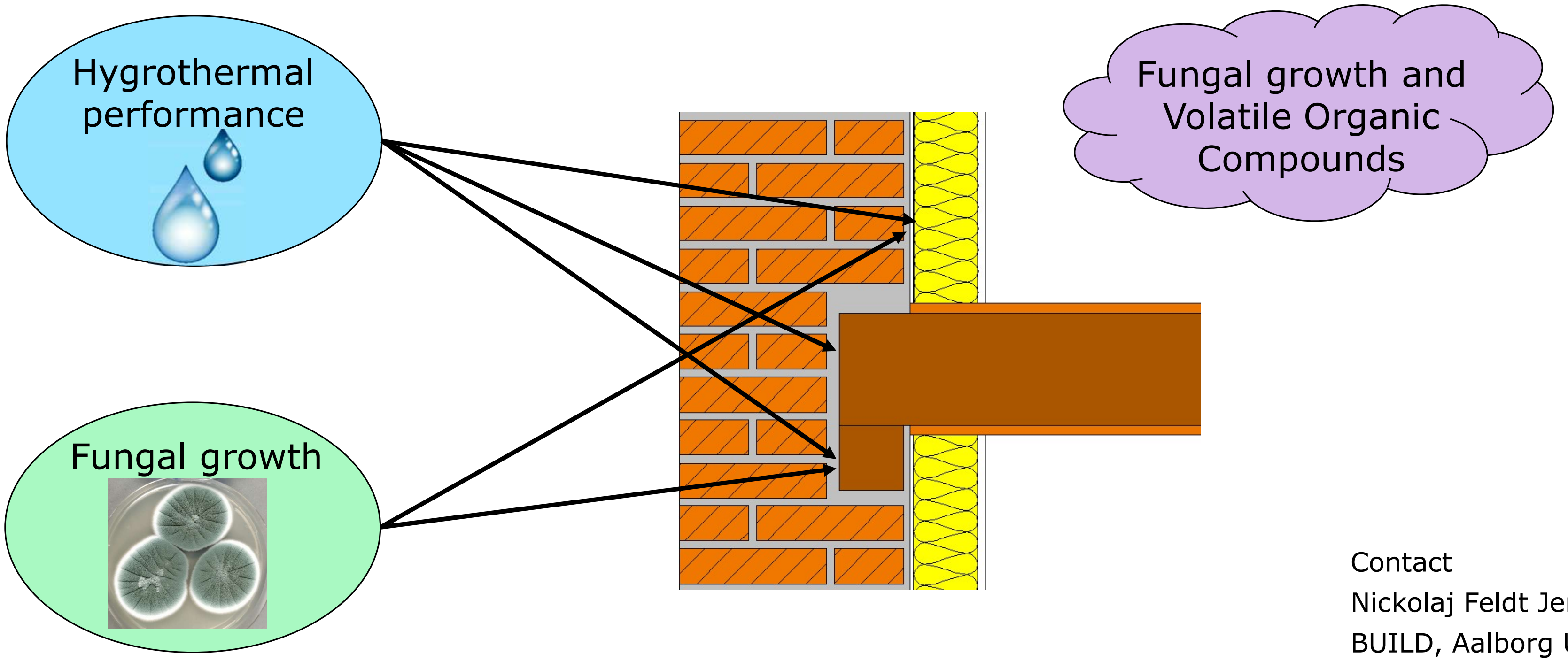
Conclusions and Perspective

- *Hypothesis 1: Moisture levels better reduced using diffusion-open, capillary active insulation in comparison with diffusion-tight insulation.*
  - Depends on whether additional measures are applied or not.
  - Best performance: diffusion-tight system with exterior hydrophobisation

- *Hypothesis 2: Fungal growth and pH level*
  - With high pH level, no fungal growth was detected despite high moisture levels
  - Diffusion tightness of the insulation system is important for maintaining high pH level

- *Hypothesis 3: Will fungal growth behind the insulation affects the indoor environment.*
  - VOCs produced by fungal growth could easily penetrate the insulation systems
  - More diffusion-tight system will protect better

Thank you for the attention



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