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Expanding Boundaries:
Systems Thinking for the Built Environment

NATURALLY VENTILATED EARTH TIMBER CONSTRUCTIONS

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Abstract

Earth, timber, fibre boards and insulation materials based on wooden and other natural fibres offer a variety of properties beneficial for eco innovative constructions that are able to improve the energy and resource efficiency of buildings.

Due to their porosity, natural building materials are vapour active and are able to buffer moisture. In combination with highly insulated and airtight but vapour permeable building envelopes, modern earth-timber constructions provide stable indoor humidity levels and can therefore be naturally ventilated while achieving highest energy efficiency standards. Experimental evidence suggests that monitored pilot buildings in Berlin do show healthy indoor air humidity levels (around 50%) in wintertime, while mechanically ventilated buildings demonstrate significantly lower values (around 25%), which have to be considered as uncomfortable and unhealthy.

The application of building materials being poor in chemical emissions, particularly volatile organic compounds (VOC) and radon, improves the indoor air quality further, so that intermittent ventilation twice a day will be sufficient to provide healthy indoor air quality. The air quality in critical rooms (e.g. small bedrooms), demonstrating a smaller air volume, should be monitored if appropriate ratios of room size to occupancy level cannot be realised.

Through night time ventilation in summer, vapour active earth-timber constructions provide evaporative cooling (humidity adsorption at night time and desorption during the day). As a result, indoor temperatures of earth-timber buildings range around 8 °C below the outside temperature peak, when an appropriate glazing ratio is reflected.

The EU funded research project H-house is investigating various construction materials regarding water vapour adsorption as well as emission and absorption of harmful substances. Based on this investigation new wall constructions are designed to provide a healthier indoor environment.

Keywords:

Climate control through building elements; hygroscopic earthen and wooden materials; natural ventilation; airtight buildings; low emissions

1 INTRODUCTION

Occupant's health, wellbeing and also productivity are relying on the indoor air quality of our built environment. Renovated and new low energy buildings, developed to be highly airtight, are demonstrating unforeseen shortcomings with regards to increased relative humidity levels and higher concentration of air pollutants. Reduced air exchange rates increase these problems and are likely to cause damp problems and condensation resulting in mould growth, and, in the worst case, in disorders and outbreak of allergic reactions.

In addition, the construction of such buildings is often based on lightweight, conventional construction materials resulting in a reduced thermal storage capacity. In combination with an inappropriate glazing ratio, such low energy buildings tend to overheat in summer and compromise occupants thermal comfort.

To overcome difficulties with moisture, dwellings nowadays are fitted with mechanical ventilation systems despite associated constraints such as space requirements, additional costs, system maintenance as well as compromised occupant comfort and control. The main criteria for ventilation are as follows:

- Control of indoor air humidity
- Absence of harmful substances
- Provision of fresh air

In case of protection against overheating in summer the provision of cooling through heat pumps or other active system is often allowed for, resulting in additional energy demand for the operation of the system, increased space requirements and an uplift in construction and maintenance cost.

It is assumed that through application of appropriate materials, the requirements on all aspects mentioned above can be satisfyingly fulfilled.

The EU funded project H-House aims to develop eco innovative partition walls for both renovation and new construction, providing affordable solutions for a wide application. In this study natural building materials have been compared to conventional materials to identify their potential to improve the indoor environment quality, while limiting the use of technology.

Special emphasis was placed on the improvement of earthen plasters by addition of aerogels with regards to both the moisture buffering capacity as well as the adsorption of airborne pollutants. For the moisture adsorption especially velocity and overall moisture uptake were investigated in greater detail.

Comprehensive experiments at material but also at component level have been undertaken to provide a database for the numerical prediction of appropriate material combinations that are able to react to different scenarios, since available surface area, occupation density, air volumes but also the construction of the building envelope might differ significantly between projects.

Accompanying experiments with regards to the emissions of the materials as well as to their potential adsorption of airborne pollutants have been conducted to identify materials that generate the most positive effects on the living environment.

In addition, experimental data coming from the monitoring of a dwelling in Berlin fitted out with earth plasters and wood fibre based partition walls has been evaluated in relation to indoor air temperatures and relative humidity levels.

2 MATERIALS AND TEST METHODS

2.1 Material selection

The material selection was based on an in-depth market analysis focused on natural building materials for internal partition walls, characterised through hygroscopic properties. In addition, natural building materials with no or limited data collection were shortlisted to close a scientific gap. Special emphasis was placed on earth plasters modified with aerogels. In the experimental campaign, the contribution to the water vapour adsorption of one type of aerogel granulate (CMSGI) and two types of aerogel powder (CMSPI and NDPI) was investigated.

Additional aspects although not presented in this contribution but equally important for the design of innovative partition walls have been investigated and taken into consideration and are:

- Low embodied energy;
- Advanced acoustic properties;
- Durability, cost efficiency.

For benchmarking purposes, also conventional construction materials have been included. In total a selection of approx. 100 materials, grouped into their function of assembly, has been investigated (Table 1).

2.2 Water vapour sorption tests

The voluntary test procedure is determined in DIN 18947 [1] to identify the capacity of earth plasters to adsorb moisture from the air via the specimen's surface within set time intervals. The test requires to pre-condition three material samples (50 cm × 20 cm × 1.5 cm) in a climate chamber at a temperature of (23 ± 1) °C and (50 ± 5)% relative humidity (RH) until constant weight is achieved. The RH level is then increased to 80% and the weight of the samples is measured at specific time intervals (0.5 h, 1 h, 3 h, 6 h and 12 h). Based on the results, the water vapour adsorption class of plasters (only) can be classified. The adsorption process is normally conducted for 12 h, however due to an increased material thickness of certain boards but also for wall build-ups the procedure was extended to 72 h (with subsequent desorption) or in case of wall build-ups to 5 adsorption/desorption cycles.

2.3 Monitoring

Monitoring data has been obtained from three different flats located in Berlin during August 2012 to September 2012 and during November 2012 to January 2013. The flats were either fitted out with natural or conventional building materials. Measurements were carried out with a miniature sensor and data logging system (iButton®) i-buttons, measuring external temperature, indoor air temperature and internal and external relative humidity [2].

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2.4 Emission tests

The materials listed in Table 1 were screened for potential emissions prior to the standard tests to estimate the compounds to be expected. Final emission tests ((S)VOCs, radon) for single materials (six types) and 13 combinations of them were carried out in specially designed test chambers over a testing period of 28 days. They were conducted following the requirements of prEN 16516 [3] and evaluated against the German AgBB scheme [4], in the absence of harmonised evaluation procedures.

Formaldehyde and VOC-analyses were carried out according to ISO 16000-3 and -6 [5], [6] and radon measurements in accordance with a procedure developed by Richter et al [7].

Function	Material	Thickness [mm]
Finishing materials	Earthen paint, marble powder paint, brush applied earth plaster, dispersion paints	0.5 - 2
Render	Aerogel modified earth plaster, earth plaster, lime plaster	3 – 15
Reinforcement	Flax fibre reinforcement, glass fibre reinforcement, system compatible reinforcement	0.5
Adhesive	Earth adhesive, system compatible adhesives	2 - 3
Wall lining boards	Earth dry & cellulose boards, wood fibre and wood fibre sandwich boards, plywood, gypsum plaster & fibre boards, Oriented Structural Straw boards	12.5 - 31
Insulation	Wood fibre insulation boards & mats, flax insulation, hemp insulation boards, sheep's wool, straw, recycled clothes, mineral & glass wool	40 - 80
Internal insulation (external walls)	Wood fibre and wood fibre sandwich boards, calcium silicate and mineral boards	20 - 100
Load bearing walls	Cross laminated timber	100
Non-load bearing, dry lining and solid wall elements (boards or blocks)	Dry lining walls based on wall lining boards (as above), earth blocks, wood fibre insulation blocks with cellulose honeycombs core, wood or gypsum fibre sandwich boards with flax core, compressed straw board, autoclaved aerated concrete	60 - 120

Table 1: Overview of investigated materials.

2.5 Adsorption of indoor pollutants

For adsorption tests according to ISO 16000-24 [8] the chamber supply air was spiked with 1-pentanol, hexanal, butyl acetate, n-decane and α-pinene representing important indoor air contaminants in specified concentrations ranging between 200 and 500 μg/m³, being higher than usually measured in indoor air to ensure a distinct determination of the reduction of the test chamber air concentration caused by the material. The air-purifying performance of the material was determined by monitoring the difference of the inlet and outlet concentration of the test chamber. Tests were carried out for more than 9 materials (six single earth plasters with and without aerogel addition, three multi-layer specimens composed of different materials).

3 RESULTS

3.1 Water vapour sorption tests

Experimental results shown in Fig. 1 and Fig. 2 demonstrate that modified and pure earth plasters are characterised through an outstanding water vapour adsorption capacity, which is up to 3 times higher in comparison to gypsum plasterboards, as evidenced also in [9], [10]. Also earth dry boards, earth cellulose and wood fibre boards demonstrate exceptional moisture buffering potential. Gypsum fibre boards range between earth plasters and gypsum plaster boards.

Additional tests have been performed for other single layered materials, but also at component level, investigating the potential of entire wall build-ups not only for the immediate moisture uptake but also their potential to provide a comfortable and healthy environment due to seasonal changes. An overview of the most relevant results is presented in *Fig. 3*. Materials were tested in the most common thickness used for standard partition wall applications and although they differ, a direct comparison of specimens seems useful to identify the most capable materials and their combination.

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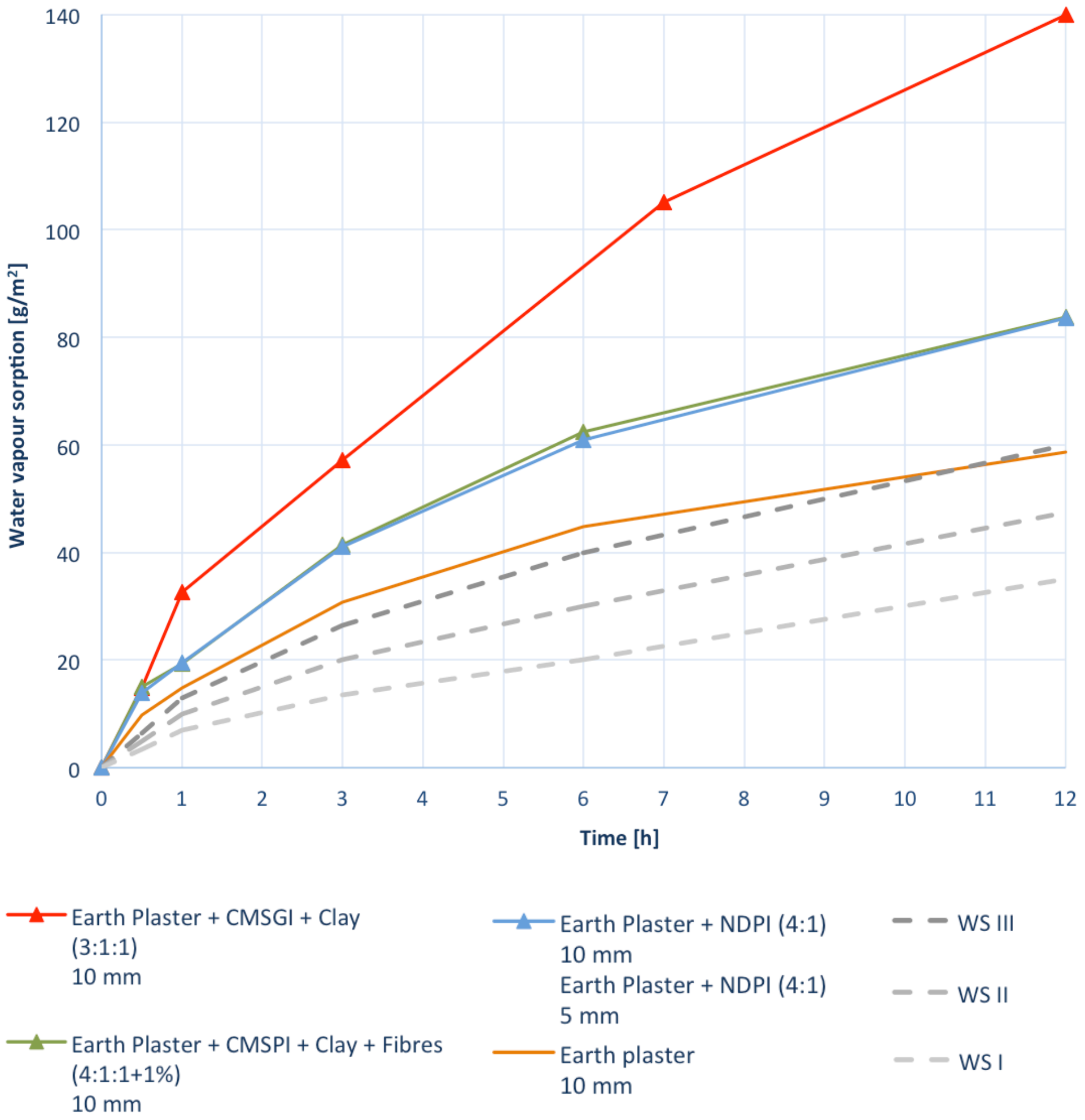

Fig. 1: Results of water vapour adsorption tests (DIN 18947) of modified and pure earth plasters (mix proportions by weight).

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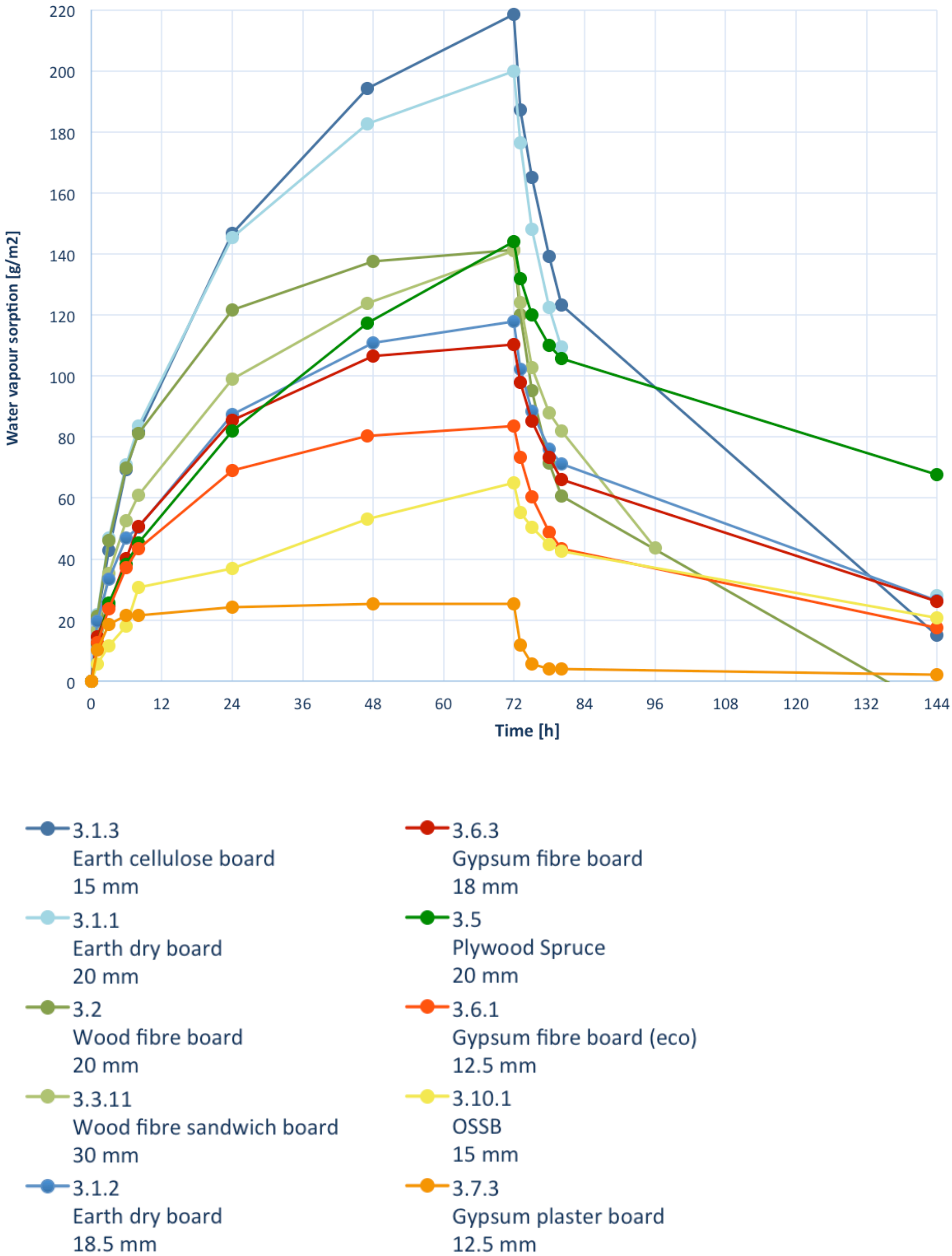

Fig. 2: Results of water vapour adsorption tests (72h) with subsequent desorption of wall lining boards.

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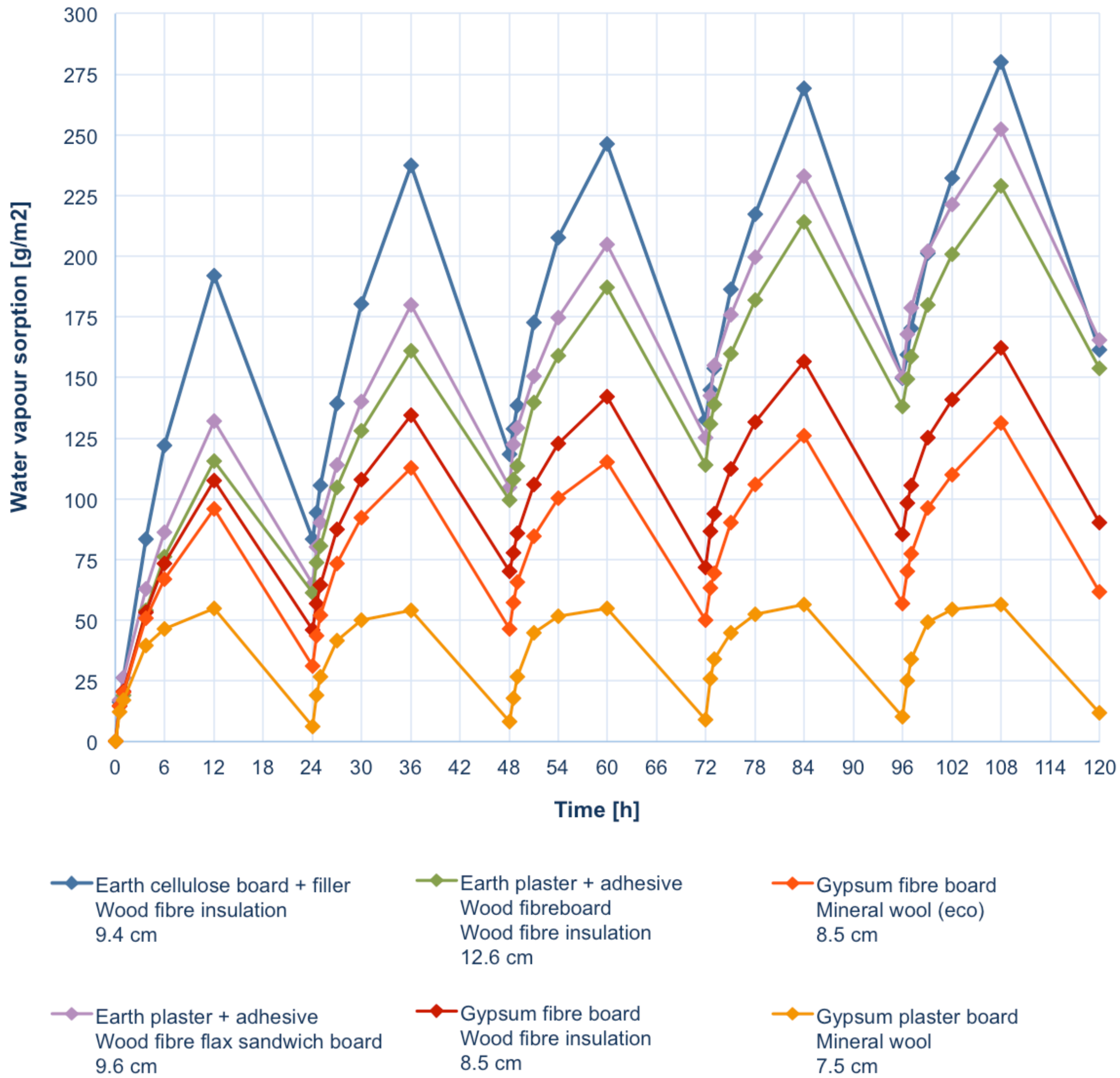

Fig. 3: Results of water vapour sorption test (5 adsorption/desorption cycles) of wall build-ups.

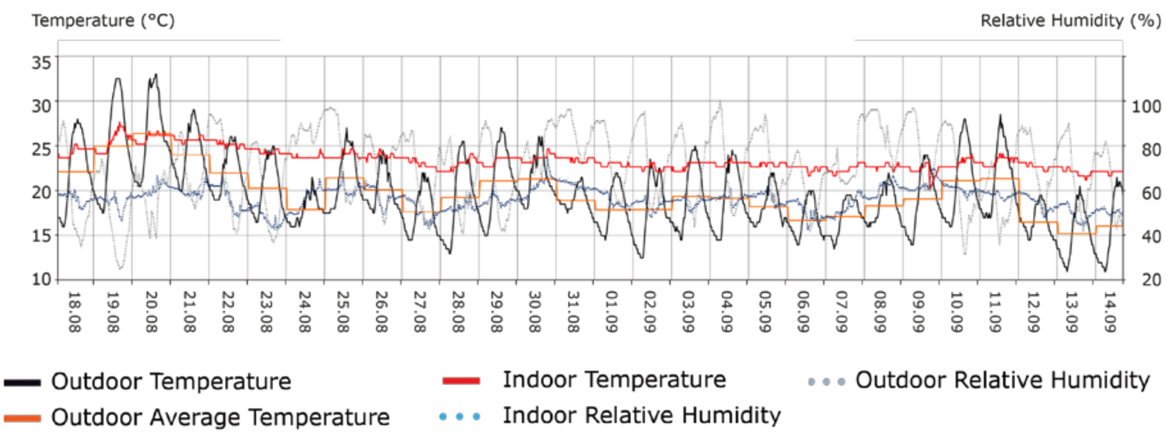

Fig. 4: Monitoring results from a living room of a flat fitted out with earth plasters.

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3.2 Monitoring

Fig. 4 shows an extract from the monitoring of the results measured in a South facing kitchen room in a flat fitted out with earth plasters and other natural building materials. Relative humidity levels were relatively stable during both periods. Indoor air temperatures were ranging always in comfortable levels, even though outdoor temperatures were above 33 °C. For the other flats, fitted out with conventional building materials relatively low humidity levels indoors during winter and higher indoor air temperatures during summer have been monitored.

3.3 Emissions tests

For all tested materials and material combinations low to very low emissions of formaldehyde, VOC and SVOC were determined. Only two of the 19 material combinations did not meet the strict requirements of the AgBB evaluation scheme. The radon exhalation from the earthen materials was low, first of all for earth plasters.

3.4 Adsorption of airborne pollutants

The results from adsorption tests demonstrated significantly different results for pure and modified earthen plasters in comparison to wall lining boards specifically designed for the adsorption of airborne pollutants. It could be shown that the addition of aerogels considerably increased the adsorption of the spiked contaminants. The best performance was observed for NDPI and CMSGI modified plasters similar to the water adsorption behaviour. In general, the polar compounds showed the strongest affinity for all the materials, the non-polar compounds have hardly attached.

4 DISCUSSION

4.1 Water vapour adsorption tests

Fig. 1 shows the potential of aerogels to increase the moisture adsorption of earthen plasters. While the addition of aerogel type ND_{PI} (powder) increased the moisture adsorption only insignificantly, the specimen modified with aerogel type CMS_{GI} (granulate) demonstrated a significant increase of moisture adsorption (> 130%) after 12 h in comparison to pure earth plasters. In addition, the adsorption speed of the pure plaster was increased by approx. 100%. The addition of aerogel type CMS_{PI} (powder) achieved similar results compared to the specimen modified with aerogel type ND_{PI} (powder), although a modified earth base plaster of 5 mm was applied, resulting in a higher plaster thickness in total. The outstanding results of the specimen CMS_{GI} enriched with aerogel granulate are most likely related to the structure of the aerogel itself. However, the amount of aerogel granulate that could be integrated into the mixture while meeting the requirements of DIN 18947 [1] is approx. 3 – 5 times higher in comparison to both aerogel powder types, being mainly responsible for the increased moisture adsorption.

The comparison of wall lining boards in *Fig. 2* demonstrates the remarkably high moisture adsorption capacity of earthen dry and cellulose boards as well as wood fibre boards in comparison to standard gypsum plaster and gypsum fibre boards. For the earth based boards the clay minerals are mainly responsible for the outstanding adsorption results, whereas for the wood fibre boards it is their high porosity and respectively high surface area. Adsorption capacity of gypsum fibre boards ranges between earth plasters and gypsum plaster boards, offering robust and good solutions, when budget and construction time becoming key factors.

Although this study is not exhaustive, it was observed that congeneric materials achieved very different results, which becomes obvious comparing the results of specimens 3.1.1 and 3.1.2 (*Fig. 2*). Similar tendencies, but even more distinct were observed for wood fibre and calcium silicate boards.

Material investigations at component level demonstrated the superior performance of natural building materials in comparison to conventional wall build-ups. *Fig. 3* demonstrates the impact of earth cellulose boards, pure earthen plasters in combination with wood fibre boards and wood fibre insulation or wood fibre flax sandwich boards in comparison to conventional wall build ups with gypsum plaster boards and mineral wool. The exact benefit on indoor air quality with regards to seasonal changes has to be determined, however it can be assumed that buildings fitted out with such walls, will benefit from evaporative cooling processes during hot summer months.

4.2 Monitoring results

Monitoring data shown in Fig. 4 indicates that temperatures in a living area facing South range 6 – 7 °C below outdoor temperatures during hot summer days, which would support the assumption that earth plasters contribute to cooler indoor air temperatures during summer through evaporative cooling.

4.3 Emission tests

It is important to note that the AgBB criteria were developed for individual building materials, for the analysis of wall systems a different set of criteria would be more appropriate. The results can therefore only have an orienting character. Nevertheless, it can be established that all other tested natural building materials were uncritical with respect to their emission properties and can be installed in buildings in almost any combination without concern.

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4.4 Adsorption of airborne pollutants

The adsorption tests revealed that earth plasters have a good adsorption capacity, which was particularly increased by the addition of aerogel granulate but also by the addition of aerogel powders.

5 CONCLUSION AND OUTLOOK

Results presented in this study suggest that low emitting, natural building materials with enhanced hygroscopic properties such as earth plasters modified by addition of aerogels, wood fibre boards, wood fibre flax sandwich boards and strawboards in combination with natural ventilation offer robust alternatives to mechanical ventilation. Through application of materials able to adsorb airborne pollutants, indoor air quality can be enhanced further. Numerical simulations have started to translate current findings into hygrothermal models for the evaluation of indoor environment quality of residential buildings. The impact of air purifying materials has to be investigated further. The models will be used to predict suitability of materials for specific applications and damage-free constructions.

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6 REFERENCES

1. DIN 18947: Earth Plasters – Terms and definitions, requirements, test methods, August 2013.

2. Klinge, A. (2013) Natural material with high hygroscopic properties in naturally ventilated buildings, Master thesis, London Metropolitan University.

3. prEN 16516, 2015. Construction products – Assessment of release of dangerous substances – Determination of emissions into indoor air.

4. AgBB, 2015. Health-related evaluation procedure for volatile organic compounds emissions (VVOC, VOC and SVOC) from building products.

5. ISO 16000-part 3, 2011. Indoor air – Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air – active sampling method.

6. ISO 16000-part 6, 2011. Indoor air – Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID.

7. Richter et al., 2013: Determination of radon exhalation from construction materials using VOC emission test chambers. Indoor Air, 23:397-405.

8. ISO 16000-part 24, 2009. Indoor air - Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials

9. Minke, G. (2012) Handbook earth construction 8th edition. Staufen bei Freiburg: ökobuch press.

10. Eckerman W. and Ziegert C. (2006) Impact of earthen construction materials on indoor air humidity (October 2006).

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