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Reducing the need for mechanical ventilation through the use of climate-responsive natural building materials

Results from the EU research project H-House and building practice

1 Introduction

More resources are consumed for the construction and use of buildings and dwellings than in any other industry. The building sector, and by extension architecture, is responsible for consuming around 50% of fossil fuels in Germany and produces around 60% of the entire volume of waste together with the resources used for the construction of buildings.

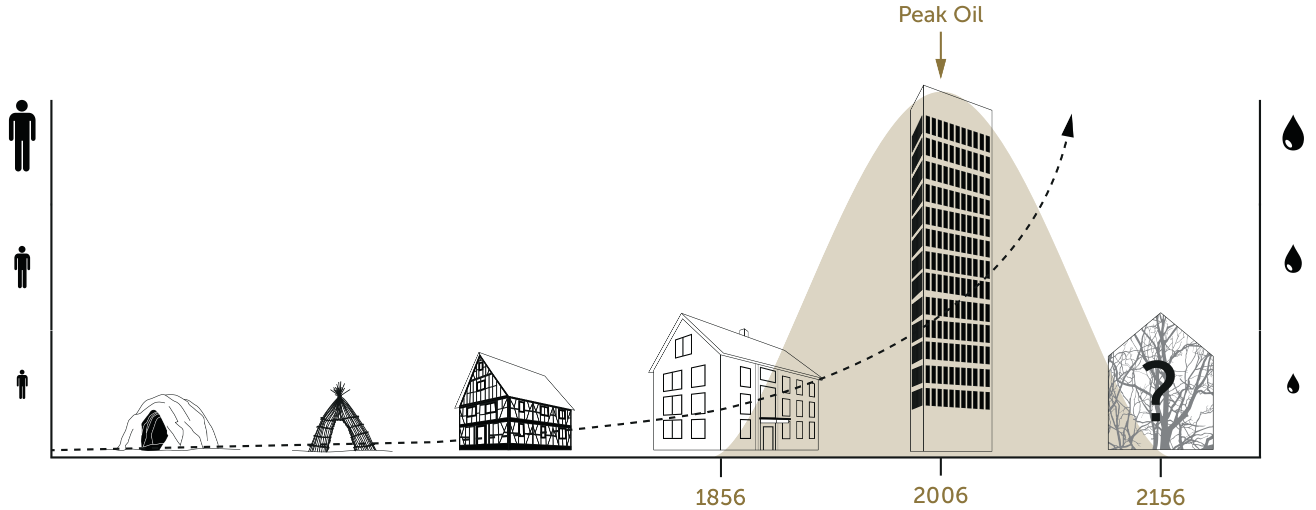
Oil, steel and concrete has led us to believe that we can overcome the laws of nature in the design of our buildings, and for years we have devised ever new technologies for controlling building climate and operating our buildings. But the onset of climate change and the continuing depletion of resources signals a need for change (Figure 1).

To achieve our declared sustainability goals, and to better equip society for the future, it is vital that we effect reforms in the building sector. Climate-adaptive architectural concepts and the use of climate-responsive natural building materials can potentially make a major contribution to conserving resources.

The health, comfort and productivity of building occupants depends to a large extent on the indoor air quality of the buildings in which they live and work. The trend towards ever more airtight building envelopes in building renovation and especially new low-energy buildings is, however, problematic for the quality of the indoor climate, resulting in high levels of relative humidity and greater concentrations of airborne pollutants. The reduced air change rates common in modern housing projects exacerbates the problem, leading to an increase in moisture and condensation-related damages such as mould formation, which in severe cases can stimulate allergies or cause people to become ill.

The standard answer to this problem is to equip buildings with mechanical ventilation systems – ideally in combination with a heat recovery system – as a means of controlling the building climate, even though this requires additional space for plant installations, entails additional costs, requires ongoing maintenance and is rarely responsive to the needs and comfort requirements of the building occupants.

Fig. 1 What comes after the unbridled consumption of the oil age?



The main criteria for the ventilation of buildings can be summarised as follows:

- Reduction of indoor air humidity in winter to reduce the formation of condensation and mould,
- Reduction of airborne pollutants in interiors,
- Reduction of CO_2 levels in indoor room air.

Traditional, natural building materials such as wood and earth, as well as natural fibres such as straw, hemp etc. have the capacity to absorb moisture and airborne pollutants and to release them again. As such, they act as natural regulators. This has been determined both by testing the materials' physical characteristics (for example Minke [1] and Ziegert and Röhlen [2]), and through the general empirical experience of living in buildings made with natural building materials.

The problem of overheating in summer is often addressed using heat pumps or other active systems for cooling buildings but this too, like mechanical ventilation systems, requires additional energy for its operation, space for the technical installations and entails additional installation and maintenance costs.

The study presented in this paper details results from the EU-funded H-House research project and offers a broad scientific basis for reducing or even obviating the need for mechanical ventilation in buildings. It begins with the assertion that we need to find more resource-efficient approaches that not only address the three above criteria but also lead to greater overall health and comfort in our living environments. It aims to show that through the combination of low-emission, climate-responsive natural building materials, a vapour permeable building envelope and an appropriate level of glazing, it is possible to design comfortable residential interiors with a healthy indoor air quality and a stable level of humidity.

This project looks at the development of innovative, sustainable but also cost-efficient (in the mid- and long-term) partitioning wall systems for new buildings and building renovations that can contribute to a healthy and comfortable indoor air quality. In particular, the project examines the use of natural building materials such as wood and earth to see how their hygroscopic properties have a positive effect on regulating indoor levels of humidity. A further test series also examined the effect of adding aerogels to increase the capacity of earth plasters to adsorb airborne moisture and pollutants. To ensure that the natural building materials do not have a detrimental effect on the indoor air quality, all materials were tested for levels of pollutant emissions.

The study also includes a comparative experimental investigation of three apartments in Berlin fitted out

Table 1 Overview of the investigated materials

Function	Material	Thickness mm
Finishing materials	Clay paint, marble powder paint, brush applied earth plaster, dispersion paints	0.5 – 2
Plaster	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
Wall lining boards	Earth drywall + 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 and 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
Loadbearing walls	Cross laminated timber	100
Non-loadbearing, 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

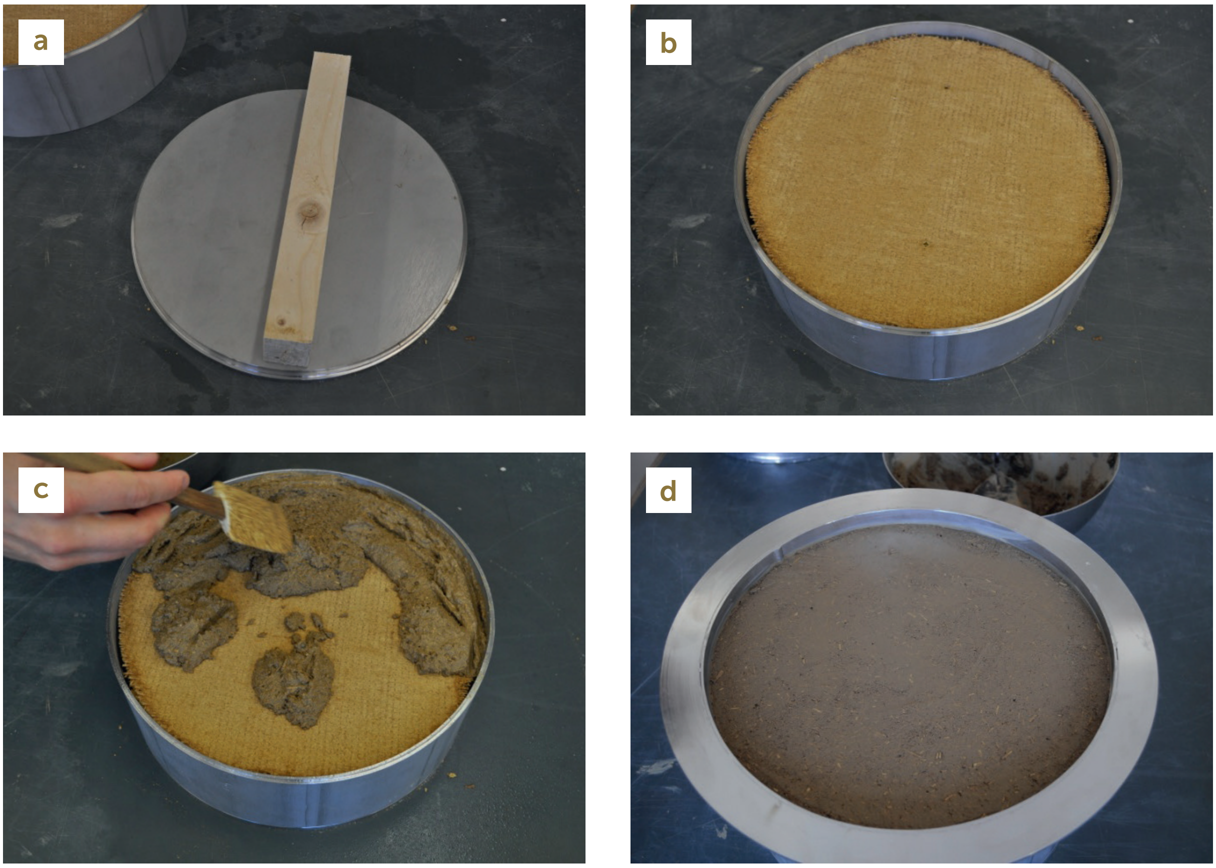


Fig. 2 Preparing a sample for testing: (a) Timber stud, (b) Earth building board with wood-fibre insulation behind, (c) Application of earth adhesive, (d) Application of the clay plaster and mounting of a flange ready for installation into the test chamber.

with a) natural and b) conventional building materials. The indoor air quality of the apartments was monitored by measuring the temperature and relative humidity.

2 Materials and testing methods

2.1 Material selection

A range of materials were selected for use with a timber and earth building system and included earth plasters, wood-fibre board, wood-fibre insulation as well as earth blocks. To increase the water vapour sorption capacity of the clay plaster as well as its ability to absorb airborne pollutants, the effect of adding aerogels (aerogel granules, CMS_{Gl}) and two different aerogel powders (CMS_{Pl} and ND_{Pl}) to the plaster were investigated. Conventional building materials used for standard internal wall applications were also investigated to serve as a benchmark. In total some 100 materials were selected and studied. Table 1 shows an overview of the materials grouped by the function they perform within the building element.

2.2 Water vapour sorption tests

The voluntary test procedure described in DIN 18947 [3] was used to determine the capacity of earth plasters to adsorb water vapour out of the ambient air. The test is carried out over a period of 12 hours. As preliminary tests showed that the maximum adsorption capacity of non-earthen natural building materials of greater material thickness had not been reached after 12 hours, and likewise that the desorption process was not complete after 12 hours (unlike for earth plasters), the test was modified to include five adsorption or desorption cycles (12 hours each) so that the capacity and potential hysteresis effects could be studied and analysed while taking into account the potentially slower desorption process.

2.3 Emission tests

In the research project, the study of emissions focusses not on the typical consideration of emissions from individual building materials but on the effect of an entire wall construction on the indoor air quality. The test requirements are detailed in the corresponding testing standards [4-8]. The wall structures were built up layer by layer within stainless steel sample holders (Figure 2) and then installed into a testing chamber designed especially for these investigations (Figure 3).

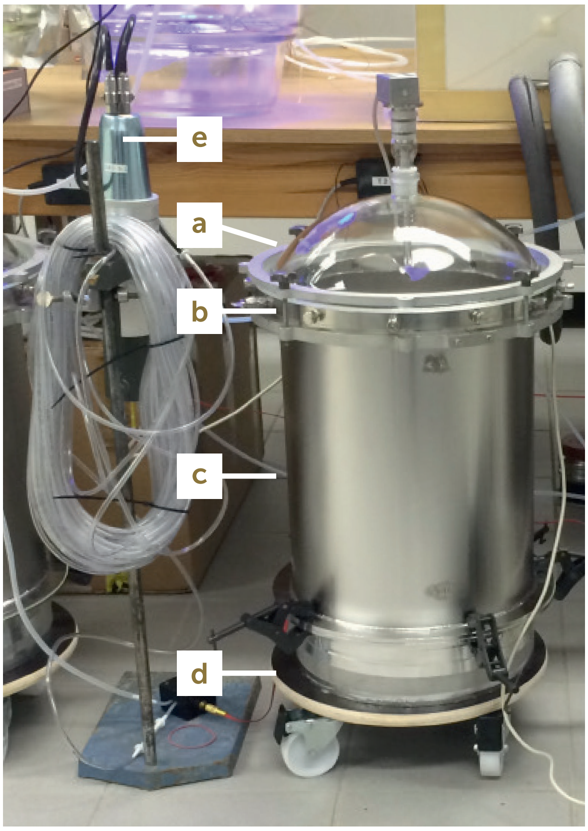


Fig. 3 Emissions testing chamber with Lucas scintillation cell for measuring radon emissions: (a) Glass cover with blade stirrer, (b) Connector ring, (c) Hollow cylinder, (d) Sample holder, (e) Lucas cell

The samples remained in the chambers for a maximum of 28 days. In many cases, however, it was possible to terminate the tests earlier as no further emissions (formaldehyde, VOCs, SVOCs, radon) were detected. The analysis of formaldehyde emissions was undertaken by sampling onto the adsorbent DNPH (2,4-Dinitrophenylhydrazine) followed by measurement with HPLC-DAD according to [4]. VOC testing was undertaken with the adsorbent Tenax TA® followed by TD-GC/MS [5] and radon exhalation using a scintillation chamber (Lucas cell). The DNPH and Tenax testing was carried out on the 3rd, 10th, 14th, and 28th day after loading the chamber, and the continuous radon measurement over a 24-hour period in the middle of the test duration.

12 individual materials and 13 material combinations from the building materials listed in Table 1 were tested for emissions. To evaluate the results, the evaluation scheme of the AgBB (Committee for Health-related Evaluation of Building Products) [9] was used. This covers the following criteria:

- TVOC (Total VOC): sum of the concentration of all individual substances with concentrations equal to or greater than 5 µg/m³ within the retention range C6–C16. The TVOC may not exceed 1000 µg/m³ on the 28th sampling day.
- ΣSVOC: sum of the concentration of all individual substances with concentrations equal to or greater than 5 µg/m³ within the retention range > C16–C22. The ΣSVOC may not exceed 100 µg/m³ on the 28th sampling day.
- Carcinogenic substances of EU categories 1 and 2 or EU categories 1A and 1B.
- Assessable compounds: All VOCs with an LCI (Lowest Concentration of Interest). These substances are listed in the appendix of the AgBB evaluation scheme; R ≤ 1.
- Non-assessable compounds: The sum of all non-identifiable VOCs and compounds with an unknown LCI. They may not exceed 100 µg/m³ on the 28th sampling day.

The so-called R-value is calculated from the measured chamber air concentrations for the evaluated materials on the 28th day of the test, or earlier if the test has run its course beforehand. It is a dimensionless sum parameter that is calculated according to Equation 1 and may not be greater than 1.

$$R_i = \sum_i \left(\frac{c_i}{LCI_i}\right) \qquad (1)$$

where c_i is the measured concentration of an assessable VOC and LCI_i is the LCI value of the assessable substance as given in Appendix 1 of the AgBB scheme.

It should be noted that in practice the scheme is usually applied only to measuring individual materials and therefore that our measurements here for sandwich elements may not be as reliable as those for individual materials.

2.4 Adsorption of airborne pollutants

These tests were undertaken in accordance with ISO 16000-24 [10] to assess the different materials' adsorption capacity of selected VOCs with different degrees of volatility and polarity (1-Pentanol, Hexanal, n-Butyl acetate, α-Pinene and n-Decane). The test procedure consists of the consistent introduction of a gas mixture comprising these components into the aforementioned test chamber at a concentration level of between 200 and 500 µg/m³ using the apparatus described in [11] and observing how the concentration decreases as a result of its adsorption by the material. The reference point for the assessment was the concentration of the introduced substance at 24 hours after loading of the test chamber. Measurements were taken after the 1st, 3rd, 7th, 14th, and 28th day after the beginning of the test, sometimes more frequently.

In all, nine material samples were tested, three of which were composite constructions comprising several components (see Table 2). To determine the adsorption capacity, the sorption flux of each individual compound (see Equation 2) and that of the entire sorption mass (see Equation 3) were evaluated.

$$F_m = \frac{(\rho_{in,t_e} - \rho_{out,t_e}) \times q_c}{A} \quad (2)$$

$$\rho_{Ac} = \sum_i \left(F_{m,i} \times \Delta t_{e,i}\right), \text{ with } \Delta t_{e,i} = t_{e,ij} - t_{e,ij-1} \quad (3)$$

where ρ_{in,t_e} is concentration of the target components after a duration t_e and ρ_{out,t_e} is the VOC concentration in the test chamber after a duration t_e, and q_c the air flow rate in the test chamber and A the exposed surface area of the material.

For the reference point in time for calculating ρ_{Ac}, the half lifetime calculated using the curve function of F_m was taken. This is the point in time at which the material exhibits half the adsorption capacity it had at the beginning of the test.

2.5 Monitoring of real spaces

Monitoring data was obtained through an empirical study carried out in three different apartments in Berlin between August 2012 and September 2012 and November 2012 and January 2013 in order to study the indoor climate. The flats were fitted out with either natural or conventional building materials. Measurements were carried out with a miniature sensor and data logging system (iButton®) iButton, which measures external temperature, indoor air temperature and internal and external relative humidity [12].

3 Results

3.1 Water vapour sorption tests

Tests were conducted at the material (Figures 4 and 5) and also the component level (Figure 6). The results shall enable planners firstly to determine appropriate material combinations in relation to specific project requirements (room size, occupation density etc.), and secondly to understand the potential of different wall build-ups to balance seasonal climatic changes while providing a comfortable climate indoors.

The test results in Figures 4 and 5 demonstrate that modified and pure earth plasters have an outstanding water vapour adsorption capacity, which is up to three times higher than gypsum plasterboard, confirming previous evidence in [1] and [13]. Also earth dry boards, earth cellulose and wood fibre boards demonstrate exceptional moisture buffering potential. The capacity of gypsum fibre board lies between that of earth plasters and gypsum plasterboard.

An overview of the most relevant results is presented in Figure 5. Materials were tested in the most common thicknesses used for standard partition wall applications and although they differ in thickness, a direct comparison of specimens seems useful to identify the most capable materials and their respective combinations. For example, earth dry boards perform slightly better than wood fibre boards despite their thinner material thickness.

In certain cases, considerable differences were also observed between different products of the same group, e.g. the earth dry boards 3.1.1 and 3.1.3 adsorb approx. 40 g/m² more than a comparable product 3.1.2 after 12 hours.

Different wall build-ups made of natural materials as well as conventional materials (benchmark) were tested over a period of five days (Figure 6). These tests made it possible, for example, to compare the effect of natural insulation materials based on wood fibre with that of mineral wool. The results show clearly that the insulation layer in the wall build-up is activated and that in the case of a gypsum fibre wall build-up, the natural fibre insulation resulted in an approx. 20% higher adsorption capacity for the overall wall.

A direct comparison of wood fibre, straw and flax with conventional constructions such as plasterboard or gypsum fibre shows that the constructions with natural materials adsorb significantly better than the conventional wall build-ups (see Figure 6).

3.2 Emission tests

In general, the emissions of all tested materials and material combinations exhibited only low to very low indoor formaldehyde, VOC, SVOC and radon concentrations. In some cases, the tests were terminated after the 10th sampling day, when the emissions were

Fig. 4 Results of the water vapour adsorption test (DIN 18947) of modified and pure earthen plasters (mixing ratios by volume)

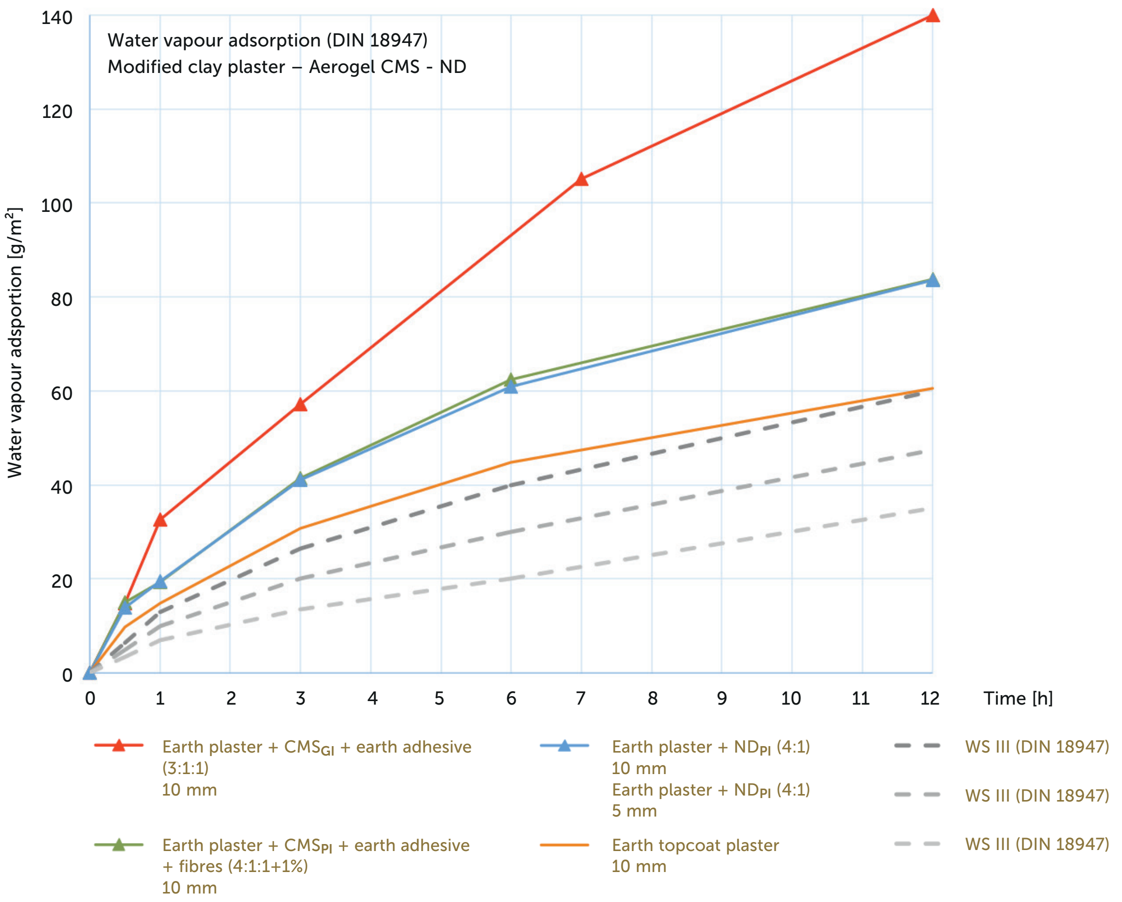


Fig. 5 Results of the water vapour adsorption test (DIN 18947) of wall lining boards

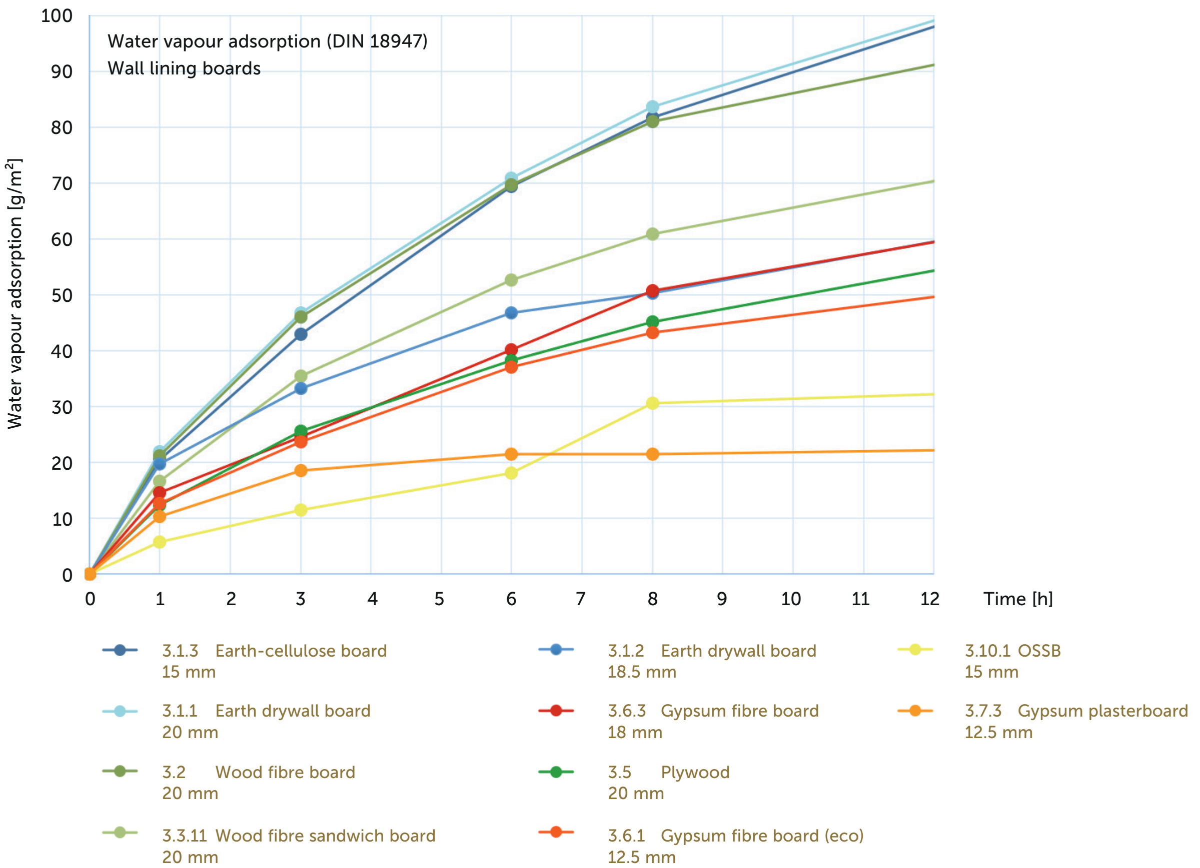
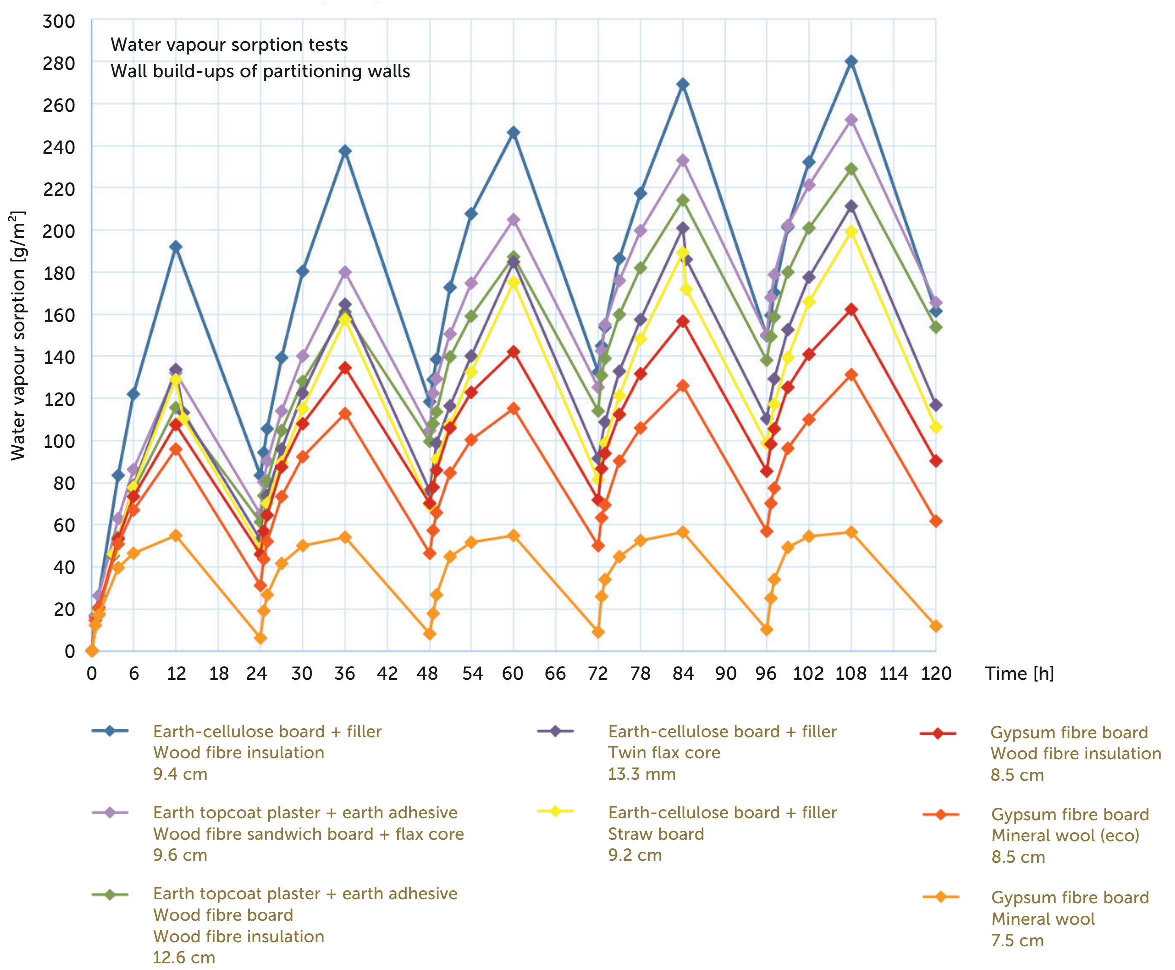


Fig. 6 Results of the water vapour sorption tests (five cycles ad- and desorption) of wall build-ups



equal to or lower than half of the AgBB requirements for the 28th sampling day.

Two out of the 25 tested materials and material combinations would not have passed AgBB evaluation if it had been strictly adopted (see 4.2).

3.3 Adsorption of air pollutants

Table 2 shows the results of the sorption tests determining the ability of the materials to adsorb air pollutants, expressed by the parameters sorption mass for each model VOC as well as the total sorption mass. The makes it possible to compare the sorption properties of the materials.

3.4 Monitoring of real spaces

Figures 7 and 8 show measurements of the relative humidity (RH) of three apartments in Berlin carried out in Berlin in winter 2012-13. As Apartment 3 is an un-refurbished building, these results are not considered in this paper. In Apartment 1 – fitted out with natural building materials – measurements were taken in the kitchen and bathroom, while in Apartment 2 – fitted out with conventional building material – measurements were additionally taken in the master bedroom. The measurements show that in Apartment 1, the level of RH remains more stable than in Apartment 2, lying mostly in a healthy and comfortable range of 50-60% with the exception of certain periods where relative humidity levels in the bathroom exceeded 60%. These were attributed to user behaviour, i.e. insufficient ventilation of the bathroom after showering. After the users were informed and adapted their ventilation behaviour, levels of RH were generally below 60%. As comparative measurements for Apartment 2 were carried out only in the period November 2012 – January 2013, only these results are presented here.

It should be noted that winter 2012-2013 was not very cold, and therefore the outdoor RH was not very low. A colder winter would probably have led to even more significant results for Apartment 2, in which the RH would have been clearly below 30%.

Table 2 Total sorption masses of the model VOCs on the tested material samples at half lifetime in mg/m³. Single materials (M) as well as wall-like build-ups (W) were tested.

No.	Wall construction	Thickness mm	1-Pentanol CAS 71-41-0	Hexanal CAS 66-25-1	Butyl acetate CAS 123-86-4	α-Pinene CAS 80-56-8	n-Decane CAS 124-18-5	Σ
1 (M)	Earth plaster with straw, final coat (EPRF)	5	7.9	6.0	12.6	0.0	0.0	26.5
2 (M)	Earth plaster with straw, final coat (EPRF) (4 parts)	5	8.7	7.9	18.0	0.0	0.0	34.6
	ND Aerogel Powder hydrophilic (NDPI) (1 part)							
3 (M)	Earth plaster fine with cellulose, final coat (EPFF) (4 parts)	3	38	21.9	27.3	0.0	0.9	88.1
	ND Aerogel Powder hydrophilic (NDPI) (1 part)							
	Earth plaster with straw, base coat (EPB) (4 parts)	12						
	ND Aerogel Powder hydrophilic (NDPI) (1 part)							
4 (M)	Earth plaster Mineral M16 (3 parts)	15	30.4	24.0	32.6	0.0	1.0	> 88.0
	ND Aerogel Powder hydrophilic (NDPI) (1 part)							
	Bamboo fibres							
5 (M)	Earth plaster fine with cellulose, final coat (EPFF)	3	3.2	3.0	5.1	0.0	0.0	11.3
6 (M)	Earth plaster fine with cellulose, final coat (EPFF) (4 parts)	3	6.6	4.2	11.0	0.0	0.0	21.8
	ND Aerogel Powder hydrophilic (NDPI) (1 part)							
7 (W)	Marble flour, chalk, vegetable casein paint	0.25	6.0	1.9	1.8	0.0	0.8	10.5
	Gypsum fibre board (for adsorption of harmful substances)	12.5						
	Joint adhesive	n/a						
	Joint filler	0.5						
	Timber stud	60						
	Wood fibre insulation mat	60						
8 (W)	Earth plaster with straw, final coat (EPRF) (3 parts)	10	36.3	32.2	57.1	0.0	0.9	> 126.5
	Clay powder (1.5 parts)							
	CMS Aerogel Granulate hydrophilic (CMSGI) (1 part)							
	Earth adhesive (4 parts)	3						
	Flax fibre reinforcement							
	Wood fibre board	20						
	Timber stud	60						
	Sheep's wool	60						
9 (W)	Filler	1.5	9	2.3	11.9	0.0	1.7	24.9
	Glass fibre reinforcement							
	Earth cellulose board	15						
	Timber stud	60						
	Wood fibre insulation mat	40						

4 Discussion of the results

4.1 Water vapour sorption tests

Figure 4 shows the potential of aerogels to significantly raise the water vapour sorption capacity of earthen plasters. While the addition of aerogel in powder form (ND_{Pl}) only slightly improved the vapour adsorption capacity, the addition of aerogel granulate (CMS_{Gl}) had a significant effect, improving adsorption by more than 130% after 12 hours in comparison to pure earth samples. The rate of adsorption could also be improved by around 100%.

The addition of aerogel type CMS_{Pl} in powder form exhibited similar results to the sample modified with aerogel type ND_{Pl} (powder form), although the ND-based sample consisted of a thicker 15 mm build-up of modified basecoat and modified topcoat plaster, and was therefore 5 mm thicker overall. This greater thickness made negligible difference to the results. The excellent properties of the sample modified with CMS_{Gl} granulate can probably be attributed to the finer structure of the aerogel itself which then has a broader spectrum of different pore sizes. However, the primary reason for the significant increase in the adsorption capacity of the aerogel granulate-modified earth plaster is the fact that three to five times more aerogel can be mixed in (by weight) for the same volume in granulate form compared with in powder form, and that without compromising the requirements of DIN 18947 [3].

The comparison of water sorption performance of wall lining boards in Figure 5 shows how well earth, cellulose and wood fibre panels perform in comparison with standard gypsum and gypsum fibre panels. The performance of the earth-based panels can be attributed in the first instance to the clay minerals, while the qualities of the wood fibre board lies in its high degree of porosity and therefore the large surface area it offers for adsorption. The adsorption capacity of gypsum fibreboard lies between that of earth and gypsum plasterboard and therefore offers a good, tolerable alternative when budget and speed of construction are the primary factors when deciding which materials to use.

Although the study is as yet not complete, one can see that similar materials can sometimes exhibit quite different characteristics. That is particularly evident in the different performance of samples 3.1.1 and 3.1.2

Fig. 7 Results of monitoring RH in winter for Apartment 1 fitted out with natural building materials

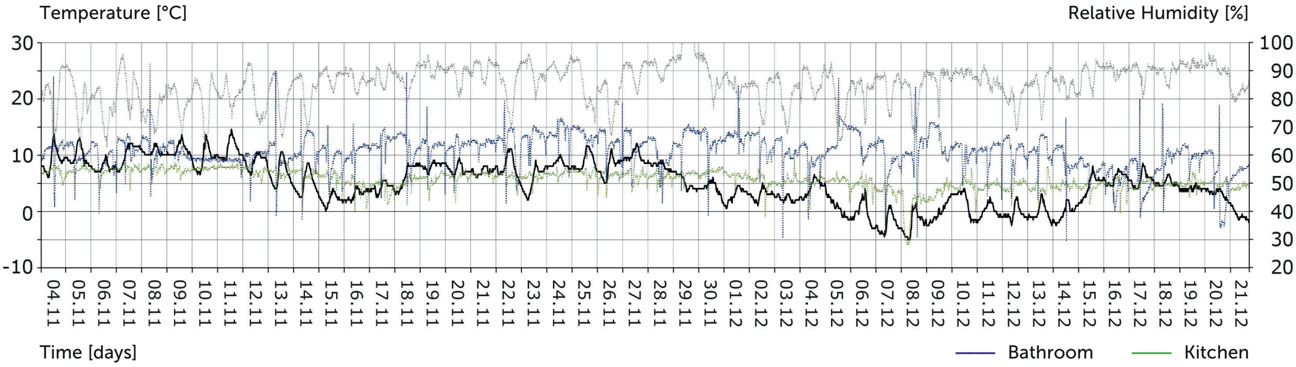
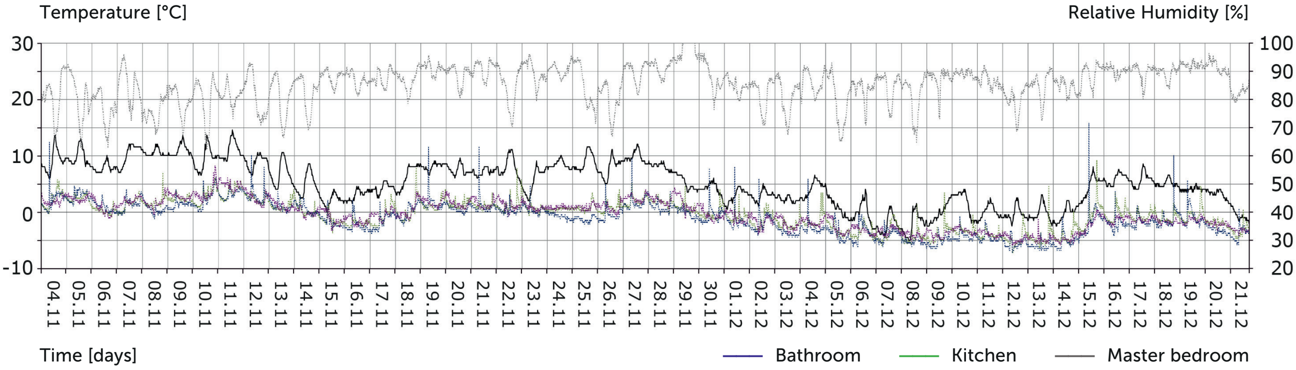


Fig. 8 Results of monitoring RH in winter for Apartment 2 fitted out with conventional building materials



(Figure 5). Similarly, even more distinct tendencies can also be observed for wood fibre and calcium silicate panels.

The material tests at a component level show the exceptionally good performance of wall build-ups using natural building materials compared to that of conventional wall structures. Figure 6 shows the effect of the earth-cellulose panels, pure clay plaster in combination with wood-fibre panels and wood-fibre insulation as well as wood fibre sandwich panels with a flax core and compares it with conventional wall structures made of gypsum plasterboard and mineral wool. While the specific benefits these offer for the indoor air quality over changing seasonal conditions need to be clarified in more detail, it is already apparent that buildings made with climate-responsive materials will benefit from evaporation cooling effects during the hot summer months.

4.2 Emission tests

Most of the materials and material combinations that were tested had clay plaster facing surfaces of different thickness, sometimes made purely of earth, sometimes modified with additives. Others employed conventional drywall plasterboard or gypsum fibre board with typical coatings or mineral-based lining boardswith natural coatings.

It is safe to assume that the emissions detected come predominantly from the outermost material layer as this is exposed directly to the space of the test chamber. However, as many of the wall build-ups are comprised of vapour-permeable materials, possible emissions from underlying layers such as the insulation, sheathing boards, reinforcement or studwork can also pass through the upper material layers and therefore be measured in the total emissions. It is also conceivable that the clay plaster, and especially the samples additionally modified with aerogels, buffer the emissions from underlying layers through the process of sorption. The results of the sorption tests (sections 3.4 and 4.4) would seem to confirm this supposition.

Almost all the materials and material combinations pass the AgBB evaluation, which means that they are suitable for indoor use. Only two samples (Figure 9a and 9b) did not pass the stricter assessment as an overall construction. In sample a, the high level of non-assessable substances [9] is apparent, and decrease significantly over the test duration. Sample b, by comparison, exhibits overall an untypical emissions profile. While sample a is comprised predominantly of earth building materials, sample b has a wood fibre insulation block (coniferous wood) with cellulose core. These insulation blocks are bonded with a special adhesive. While some of the emissions from this wall construction can be attributed to the timber construction elements (Pentanal, Hexanal, 2-Furaldehyde), the alkane compound emissions (C11 to C13) are very probably from the adhesive. However, the primary reason why samples a and b are deemed potentially unsuitable for use in interiors according to the AgBB scheme is the high proportion of non-assessable substances in the overall concentration of emissions at the 28th day (>0.1 mg/m^3), the origins of which are hard to determine.

The use of the AgBB scheme in our tests can only serve as general orientation as the test procedure was originally developed for individual building materials and not for combinations thereof.

Radon is not part of the AgBB evaluation scheme. In all cases the measured values are of a very low concentration, barely above the detection limit.

4.3 Adsorption of airborne pollutants

As can be seen in Table 2, samples number 3, 4 and 8 have the best sorption capacity, followed by sample number 2. The wall construction of number 8 in particular performs particularly well, although it should be noted that the clay plaster at the edge of the sample holder had shrunk very slightly at the edge after insertion into the test chamber and there is therefore a possibility that test gases may have penetrated through this gap to the underlying layers, affecting the test result.

All four samples are coated with clay plasters of varying compositions. The clay plaster of samples number 2, 3 and 4 contain added aerogel ND_{PI} which improves the VOC sorption capacity considerably, as can be seen clearly by a comparison of the samples 1 and 2 and 5 and 6. Whether the addition of aerogel CMS_{GI} to sample 8 contributed to its comparatively good sorption capacity cannot be categorically determined due to the reason given above.

The sorption mass of samples number 4 and 8 are given with ">". This means that the half lifetime had

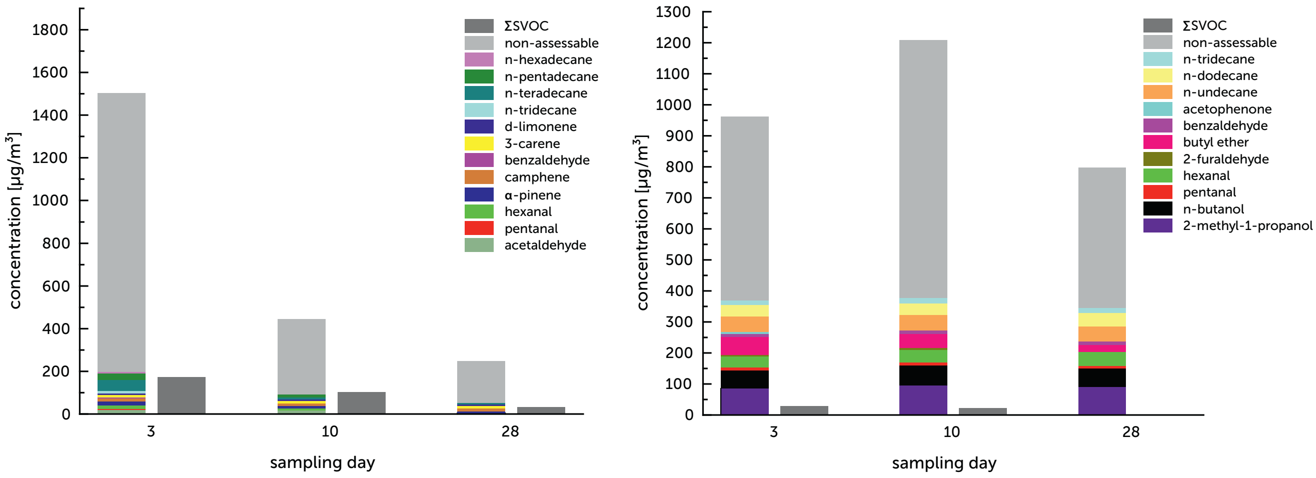


Fig. 9 Emissions from two samples that would not be suitable for use in interiors according to the AgBB scheme

not been reached by some substances by the end of the test in the test chamber after 28 days.

In addition, we can identify that the sorption capacity of the plasters for the VOCs in the gas mixture reduces with decreasing polarity of the substances. The polar compounds 1-Pentanol, Hexanal and n-Butyl acetate exhibit the greatest potential to be absorbed. Of the two non-polar VOCs α-Pinene and n-Decane, only n-Decane is absorbed to a small degree in samples number 3, 4, 7, 8 and 9.

4.4 Monitoring of real spaces

The results of the monitoring of real spaces (Figures 7 and 8) shows that the relative humidity of the rooms in the apartment fitted with wood fibre and earth plaster was consistently in the region of 50-60%, which can be attributed to the buffering capacity of the earth, as discussed also in [1] and [12]. The low level of relative humidity of ~30% in Apartment 2 fitted out with conventional building materials can be attributed in part to the mechanical ventilation system that draws in dry air from outdoors all day, and in part to the materials used, that are unable to adsorb significant quantities of moisture arising within the apartment as a result of cooking or showering.

5 Potential for building practice – examples

5.1 Technical principles for building without mechanical ventilation systems

The investigations undertaken as part of the H-House project concern internal walls and the internal face of external walls, focussing on natural building materials as internal insulation. The project shows that natural building materials are particularly well-suited for naturally regulating humidity levels in interiors and trapping airborne pollutants. This same principle can also be applied to the building skin as a whole and to structures made of wood, earth and natural fibres.

In the design of elements of the building skin (i.e the walls and roofs exposed to outdoor air) it is becoming common practice, in timber construction at least, to design vapour-permeable structures that do not have vapour barriers or retarding layers [13].

So how do such well-insulated, energy-efficient and airtight buildings made of wood, earth and other natural fibres perform with regard to addressing the criteria for ventilation needs and indoor air quality discussed earlier?

Assuming that such buildings are well-aired twice a day – once in the morning, once in the evening – by opening the windows fully, one can assert the following: The natural building materials investigated in the H-House project are able to regulate indoor humidity levels in normal domestic situations to a level between 40 and 60% RH. This level is dry enough to exclude the risk of mould formation but humid enough to counteract the risk of illness through viruses [14]. Timber and earth constructions are healthy and comfortable precisely because they do not need additional mechanical ventilation.

The level of pollutants in indoor environments is largely a product of the materials used. By using the right building materials from the outset, one immediately reduces source of pollutants in buildings to a healthy level. Earth building materials can additionally bind airborne pollutants, releasing them again when the room is ventilated so that they are transported out of the building.

Consequently, the main criteria that needs addressing in the design of timber and earth constructions is the reduction of CO_2 levels in the air. CO_2 in indoor environments comes mostly from the air exhaled by its occupants. The level of CO_2 within a space is therefore a factor of the volume of air available to each person, i.e. the number of people in a room and the size of the room. In a small bedroom in which two adults sleep with the door closed, this can be critical, but if the door is opened, the volume of air is sufficient to keep CO_2 levels in the desired region of < 1000 ppm.

The use of mechanical ventilation systems is currently a topic of much debate. The German DIN standard 1946-6:2009-05 [16] outlines current ventilation requirements. This norm was elaborated by the DIN Standards Committee for Heating and Ventilation Technology and entirely discounts manual ventilation – opening of windows – as a means of regulating moisture levels and preventing mould formation. This norm is currently heavily criticised and does not reflect the “generally accepted current state of the art”. In any case, there is a high liability risk because the norm is open to different legal interpretation. Even if one opts to install mechanical ventilation, one may lay oneself open to the charge of incurring excessive costs or of creating a health risk because the room climate is too dry.

The measurements described above, undertaken by Ziegert Roswag Seiler in different reference apartments in Berlin, show that if an apartment is sufficiently ventilated by opening the windows twice per day, mornings and evenings, this is sufficient to keep CO_2 concentration at a sufficiently low level. The most important aspect is to maintain indoor humidity levels at a stable, healthy and comfortable level of 45 – 60% RH, especially in winter.

The monitoring of temperature levels also revealed that natural building materials were able to reduce heat gains in summer in comparison to conventional building structures. The indoor air temperature on hot summer days was around 8°C less than the peak outdoor temperature and always below 30°. This phenomenon can be attributed to the high sorption capacity that enables rooms to cool down more effectively when ventilated at night.

5.2 Climate-responsive building systems using timber, earth and natural building materials

For the design of timber and earth buildings, a key criterion is an appropriate degree of glazing. A good balance needs to be found between solar gain and heat loss in winter and heat gain in summer, while ensuring that windows provide sufficient natural illumination. The remaining solid, vapour-permeable sections of the building envelope are the parts of the building that contribute to climate-control and the comfort of the interior for its users.

Fig. 10 Climate-responsive building concept without mechanical ventilation

Climate-responsive timber and earth building system

01 Soil
02 Foundation: Foam-glass insulation, reinforced concrete
03 Walls: Timber with cellulose insulation
04 Roof: Timber with cellulose insulation
05 Ground floor: Underfloor heating
06 Internal walls: Timber stud, earth plaster
07 Intermediary floors: Solid wood
08 Finishes: Clay plaster to regulate indoor climate
09 Passive solar energy gain via windows
10 Heating: underfloor heating
11 Power: Solar energy collectors
12 Water: Stratified hot water tank with integral gas boiler
13 Backup heating: wood-burning fireplace

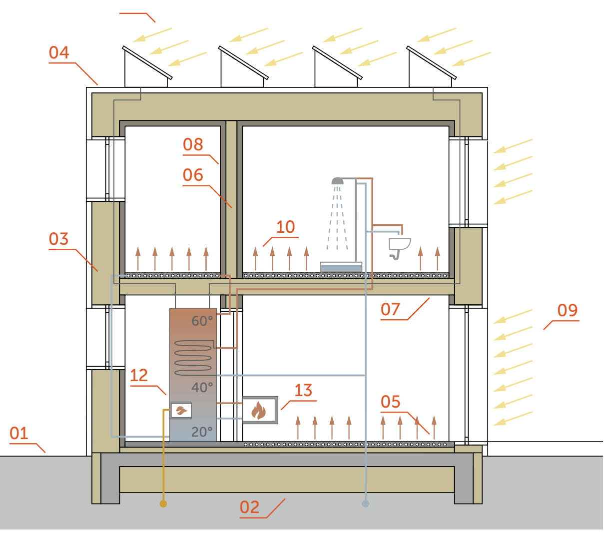


Fig. 11 Wood and earth wall with wall-heating pipes prior to embedding in clay plaster (Torfremise)

As with all energy-optimised buildings, the solid walls of the timber and earth building have a very low U-value of between 0.15 and 0.10 W/m²K. A simple timber-frame wall construction of 6 × 30 cm posts, clad on each side with wood-fibre panels is sufficient to achieve such values. The wood-fibre panels serve as a windproof membrane without the need to seal the building with foil or vapour barriers. The internal face is typically plastered with a clay plaster, where required with embedded wall-heating, while the outside face is lined with a rear-ventilated façade. Blow-in cellulose or wood-fibre insulation fills the cavities between the timber posts. The combination of capillary conductive natural building materials and the vapour-permeable wall construction results in a robust, durable and largely pollutant-free building system. For the windows, triple-glazed timber-framed windows are suitable, their frames covered as far as possible by the insulation layer to reduce the risk of condensation forming on the windows on cold winter days (Figures 10 and 11).

5.3 Building in lifecycles

A timber and earth building with a highly-insulated external skin and appropriate degree of glazing needs comparatively little energy, especially if combined with integral heat and power collectors. This constellation is largely climate-neutral. By using energy from renewable sources, it is possible to almost exclusively do without non-renewable fossil fuels.

Further research and development is required into resource-efficient alternatives for foundations that do not require steel and concrete. Similarly, future structures should be designed with reversibility, re-use and recyclability in mind. This enables them to be dismantled and re-used for other purposes at a later date when the building is adapted or no longer needed.

5.4 Examples

The historical "Torfremise"

Until 2005, the historical former peat barn in Schechen stood on another site altogether, where it was scheduled for demolition to make way for a new development. The owners elected instead to dismantle the timber structure and re-erected it a few years later at another location. The structure was given a new foundation and converted through the insertion of a new near-zero-energy house. The highly-insulated timber and earth construction obviates the need for mechanical ventilation. A solar water heating system backed up by a wood-burning stove for heating material offcuts and wood from the owner's own stock of trees means that the home and workshop is climate-neutral. Additional solar collectors on the roof have been proposed, in which case the building would produce more energy than it consumes.

Fig. 12 Reversible timber constructions in both the new and old parts of the "Torfremise" in Schechen

Fig. 13 Flexim GmbH, Third floor prior to fitting out and rendering of the exterior and entrance area

White clay facing plaster and soap-treated pine flooring dominate within. The historical structural frame of the building, mostly rough-hewn with an axe, was cleaned and oiled after re-erection. The projecting eaves and the placing of the new walls offset behind the historical slatted façade made it possible to use clay facing plaster on the outside walls too. The new building is therefore articulated as an independent white volume within the framework of the existing building – new and old intertwined (Figure 12).

New premises for Flexim GmbH, Berlin

The new premises for Flexim transfers the principles of the H-House project to an industrial factory building of approximately 14,000 m^2 gross floor area. The building envelope is a vapour-permeable wall construction clad on the internal face with gypsum fibre board. While the adsorption capacity of gypsum fibre, at approx. 45 g/m^2, is about two-thirds that of clay plaster, it is three times that of regular plasterboard. For this commercial building it represents an appropriate compromise between price and performance. The internal walls are likewise gypsum fibre board walls with a natural fibre insulation within to help regulate the indoor climate. In addition, the exposed ceilings of the timber-concrete composite floor slabs also act as a further significant climate-responsive surface (Figure 13).

Acknowledgements

This research project was made possible through the support of the European Union's 7th Framework Programme for research, technological development and demonstration under grant agreement no. 608893 (H-House, *www.h-house-project.eu*).

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