

New sustainable and insulating building material made of cattail

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KEYWORDS: Insulation, sustainability, cattail, half timbered framework, heritage

SUMMARY:

Due to the special structural properties of cattail (typha) building materials can be produced offering a combination of insulation and strength, which is unique on the market. The leaf mass of typha is especially suited due the structure of the plant. The leaves have a fiber-reinforced supporting tissue filled with soft open-cell spongy tissue providing for amazing statics and an excellent insulating effect. In the past few years, the Fraunhofer Institute for Building Physics investigated various product developments in cooperation with the inventor Dipl.-Ing. Werner Theuerkorn. The newly developed magnesite-bound typha board has an extremely high strength and dynamic stability despite a low thermal conductivity of about 0.055 W/mK and can solve energetic as well as static problems. This innovative building material possesses a lot of positive properties. With the typha board as infill of the timber frames and as an additional inside insulation layer an extremely slender exterior wall construction with wall heating is realized. Due to the simple processability and inherent stiffness the material could be adjusted to the irregular inclined walls. The suitability of the wall structure has been investigated over a measuring period of 1.5 years. The U-value of the whole building (infill and timber construction) is about 0.35 W/m²K. The low level of moisture applied by the mortar and plaster dried out fast to a constant moisture contents in the wooden supports of below 20 M.-%.

1. Introduction

Cattails are, due to their enormous growth rate and yield, optimally suited as raw material for industrial use. Typha stock (Fig. 1, left) comprises resilient, natural monocultures with an annual production rate of 15 to 20 tonnes of dry matter per hectare. This corresponds to four to five times the amount that local evergreen forests produce. Cattail crops create ecologically precious wetlands, which fulfill other important functions besides the absorption of nutrients and CO₂ (Faulstich 2012). Cultivation in lowland moors and valley plains in Germany would offer a sufficient basis to cover the total demand for insulation and wall construction materials. The special structural characteristics of cattails support the production of construction materials that offer a unique combination of load bearing capacity and insulation. The plant's structure (Fig. 1, right) entails the particular suitability of the typha leaf mass for creating innovative building materials (Pfadenhauer 2001, Theuerkorn 1998). Due to the combination of tensile strength of stem fibre and elastic sponge-like tissue, leaves are tear and break resistant, flexible and maintain their shape even in dried condition. These characteristics provide remarkable load-bearing capacity and excellent insulation properties. Behaviour of leaf mass under tensile and compressive stress is completely different along the leaf axis from base to tip than perpendicular to it: along the axis, the leaf material resists high compression loads of approximately 1 N/mm and even higher tensile stress. Perpendicular to this axis, elastic deformation sets in already at very low stress of 0.01 N/mm and predominantly remains within reversible ranges.



Fig. 1. Typha sprout with leaf fan, left picture by TU Munich and section of a typha leaf, right picture by Chr. Gruber BLfD

The special qualities of typha insulation panels originate in these diverse characteristics. Their production is based on laying out typha-leaf particles randomly, yet parallel to the panel plane and binding them with magnesite. The result is a material that can be created within a relatively simple procedure. This product contains only plant ingredients, purely mineral-based adhesive and no further additives. Thus, it is completely compostable. At the same time, it features a beneficial ratio of compressive strength along the panel plane, thermal conductivity, vapour diffusion properties, as well as storage mass for summertime heat protection. Variations in strength values and insulation capacities depend on bulk density and the percentage of magnesite (Table 1).

Table 1: Measured heat conductivities and bearing loads for different bulk densities and parts of magnesite bond, from Theuerkorn (2013).

Type	Density [kg/m ³]	Magnesite part [%]	Bearing load [N/mm ²]	Heat conductivity* [W/Km]
1a	257	50	0,54	0,055
1b	283	60	0,46	0,058
1c	233	40	0,34	0,053
2a	237	50	0,36	-
2b	243	60	0,36	-
2c	217	40	0,29	0,048
3a	318	50	1,01	-
3b	346	60	0,76	0,061

* orientative, not normative measurement

The complete range of hygrothermal key values was registered for a material sample with a particularly effective combination of stability and thermal conductivity. The material, despite relatively high bulk mass and high solidity, features a comparably low thermal conductivity of 0.055 W/mK and displays capillary action at a medium vapour diffusion rate (Table 2). By using it, vapour barriers could be avoided completely in many applications. Moreover, this innovative building material possesses a lot of other positive properties:

- renewable building materials with a very high resistance to mould growth
- good protection against fire, noise control and thermal insulation in summer
- simple processability with all common tools
- relatively diffusion open and capillary active
- low energy consumption in production
- recyclability.

Table 2: Hygrothermal material properties of type 1a.

Material property	Unit	Result
Bulk density	kg/m ³	270
Porosity	Vol.-%	75
Diffusion resistance dry-cup (23 0/50)	-	28
Wet-cup (23 50/93)	-	20
Water absorption coefficient	Kg/m ² √h	1.1
Sorption moisture content 23 °C 65 % r. H:	Vol.-%	0.65
23 °C 80 % r. H:	Vol.-%	1.2
23 °C 93 % r. H:	Vol.-%	2.9
23 °C 97 % r. H:	Vol.-%	6.9
Capillary saturation	Vol.-%	59
Heat conductivity	W/mK	0.055

2. Insulation of half timbered framework

Due to the immanent energy transition, new requirements are also placed on historic buildings. In general, they can hardly be met. This is why it is necessary to develop new materials and concepts for energy optimization meeting historic preservation needs specifically for such objects. The newly developed building material made of cattails seems appropriate for the task. In the case of a timbered building in Nuremberg with asymmetrical design and inadequate bracing of the structural frame (see Fig. 2, left) the timbers were supposed to be made visible again - while maintaining EnEV 2009 regulations as well as historic preservation requirements (Theuerkorn 2013; Fritsch 2013), and at the same time, providing stability to the building. These requirements were met by employing typha-panels. The model project made use of the material and was supported by the Federal German Foundation for the Environment and the Bavarian State Office for the Preservation of Historical Monuments. After comprehensive research on the existing construction, the details for the wall composition were designed and realized in close cooperation with construction management and craftsmen. A model frame served to develop a slender exterior wall construction of only 20 cm depth featuring integrated wall heater (Fig. 2, right).



Fig. 2. Condition of the wooden framework before restoration (left) and scheme of the insulation (right), pictures by Alexandra Fritsch.

The framework timbers were covered with slats according to carpentry standards for renovating such structures. The typha panels were cut to provide a continuous 10 mm wide groove. First, external panels with a thickness of 60 mm were fixed on the outside to the slats with drywall screws and

washers. A second panel with 60 mm thickness was fit internally and connected to the external panels with screws, while leaving a gap between the edge of the interior panels and the timbers. To enable wind proofing and force-fit connections, the gaps between timbers and typha panels are infilled with a typha-based joint compound. The seams are covered and smoothed with a taping knife. By including ground typha material, the joint compound can expand if water is introduced later on. After creating a uniform plane wall surface by use of compensating panels, additional 40 mm thick typha panels were attached to the interior wall. Due to panels being screw-tight and easy to render, their surface served to directly mount wall heat pipes with screw connectors. Voids were infilled with a lime-gypsum based mortar. The finishing coat is a loam render enriched with cattail seed parachutes. This render reinforcement is an effective means to ensure crack resistance without a fabric lining. Fig. 3 shows the layout of the construction.

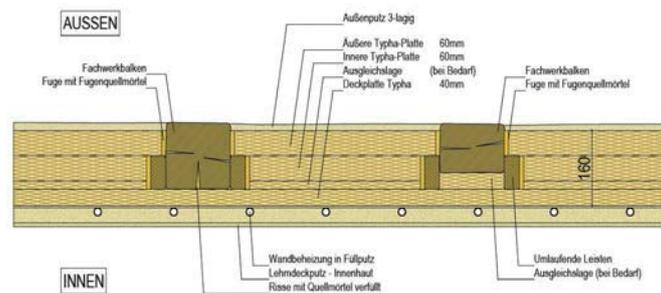


Fig. 3. Layout wall structure planning guide, picture by Fritsch+Knodt&Klug.

The functional capability of the wall construction was tested by monitoring during a one and a half years testing period. For this purpose, sensors were distributed along the cross section of a selected infill area to determine temperature, relative humidity, wood moisture, and heat flow (Fig.4).



Fig. 4. Outer sensors at layer 1 beneath the outside rendering (left) as well as Temperature sensor, heat flow wafer and humidity sensor on barrier layer 3, beneath internal insulation on the second insulation board layer (right).

The course of boundary layer temperatures as hourly average values from January 2011 to September 2012 is displayed in Fig 5, left. The typical thermal stratification from the interior (room air temperature RLLT / interior surface temperature IOFT) to the exterior along boundary layer 4 (GS4T) is evident. Prior to operating the wall heater, the space was heated via an open door to the heated neighbouring room. The initial adjustment attempts of the renter after begin of operation clearly display excessive use (marked by a blue circle). Fig 5, right side, shows the measured heat flow behind the interior insulation (boundary layer 3) and the temperature distribution along this area, as well as the exterior along boundary layer 1.

The thermal insulation characteristics of the wall construction can be calculated based on this heat flow in relation to the temperature difference. Two selected measuring periods (indicated in orange)

result in a heat transfer coefficient (U-value) of 0.26 W/m²K, taking the additional interior insulation into account. For the entire construction including frame timbers the result is a value of 0.31 W/m²K. Since measurements also include thermal gains due to solar intake (including diffuse irradiance), this heat transfer resistance is called “relational” U-value.

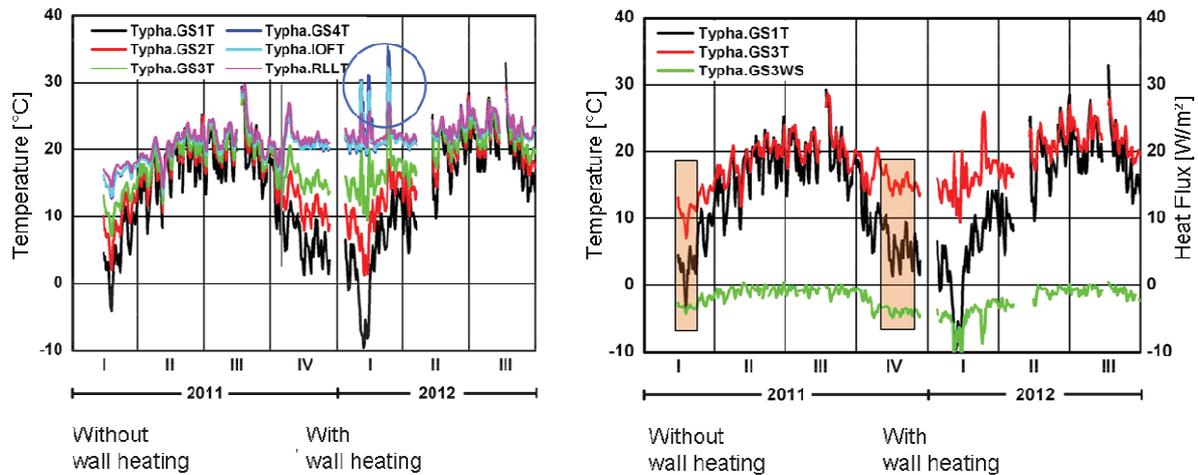


Fig. 5. Measured course of the temperature as daily mean values for the period from January 2011 to September 2012 (left) and heat flow measured behind the internal insulation (layer 3) with course of the temperature at layer 1 and 3. The bars show time periods suited for assessing the thermal resistance (right).

When calculating the “real” U-value based on the material properties, the outcomes are slightly higher values of 0.29 W/m²K for the infill and 0.35 W/m²K for the entire construction. Due to the building moisture that is introduced via the exterior render and the relatively good absorption capacity of wood, the results show a very high initial wood moisture content of more than 100 %. However, drying occurs quickly, and the wood moisture content of all four measurement areas along the wood surface located immediately behind the exterior render layer decreased to 20 % (Fig. 6).

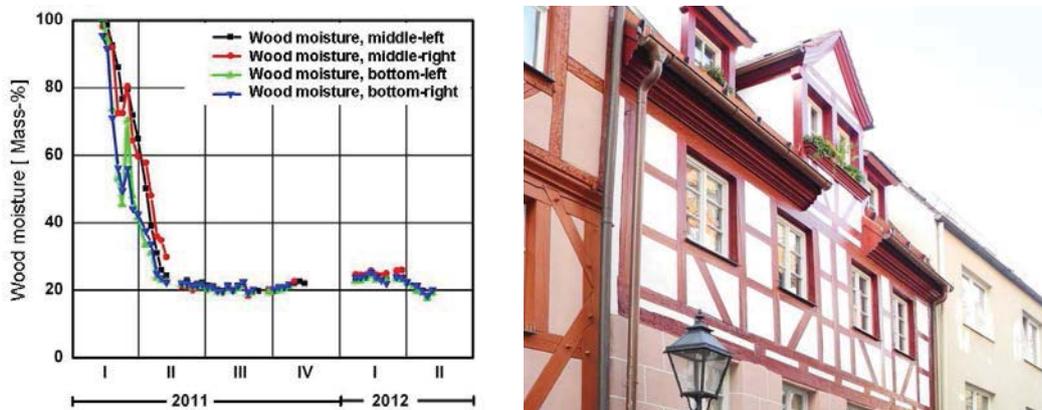


Fig. 6. Course of the wood moisture (left) and view of the building after restoration (right).

By adding the typha panels as a combination of infill insulation and interior insulation, a heat transfer coefficient of approximately 0.35 W/m²K was achieved for this wall construction - at an overall wall thickness not exceeding 20 cm, including wall heater. For a timbered building, this is an extraordinarily good result. The measurements of temperatures and air humidity undertaken across two heating periods prove the suitability of the construction in regard to building physics. Altogether, the entire insulation procedure based on applying magnesite bonded typha panels comprises an extremely effective solution in terms of building physics and historic preservation.

3. Calculational investigations for the magnesite-bound typha board as internal insulation on masonry

The half-timbered building in Pfeiffergasse in Nuremberg has a ground floor of massive masonry as many other buildings of the same kind. For the energetic restoration of this building it was planned to install an internal insulation by magnesite-bound typha boards of a material thickness of 4 cm furnished with fiber-reinforced clay plaster. The boards were installed edge to edge and fixed by dowels on the internal surface of the external wall. Since an accompanying measurement was not planned due to financial reasons hygrothermal calculations were carried out to assess whether this measure will be free of damage. The IBP developed a proved and frequently validated one-dimensional and two-dimensional computer program WUFI[®]-Pro (Künzel 1994) for the calculation of coupled heat and moisture transfer processes. Previous descriptions of the moisture transfer behavior of building materials by means of this method have achieved good compliance of calculation and practical investigations of the test specimen (Krus 1996; Künzel 1999).

Climate data of Holzkirchen are used as climate boundary conditions allowing assessments on more unfavorable weather conditions than those in Nuremberg. Living conditions with normal moisture load (meaning normal use of living areas) serve as indoor climate. The heat transmission coefficients are 8 W/m²K on the inside and 17 W/m²K on the outside. Material parameters of the masonry and clay plaster are taken from the WUFI[®] material database. Calculations of the typha board are based on the hygrothermal material parameters determined before. If necessary, it is possible to assess by means of the prognosis tool WUFI[®]-Bio (Sedlbauer 2001; Sedlbauer 2003), whether mould growth may occur. Since an all-over contact of the typha board with the brick work cannot be secured a thin air layer was suggested between insulation and masonry.

If the most critical point of the wall between external wall and internal insulation is considered, the characteristic seasonal fluctuations of temperature and humidity can be observed. Maximum relative humidity of approx. 65 %, however, is achieved in this point (Fig. 7, left). Therefore, mould growth can be excluded. The calculation results show that no moisture damage will occur in case of careful implementation with good permanent convection tightness.

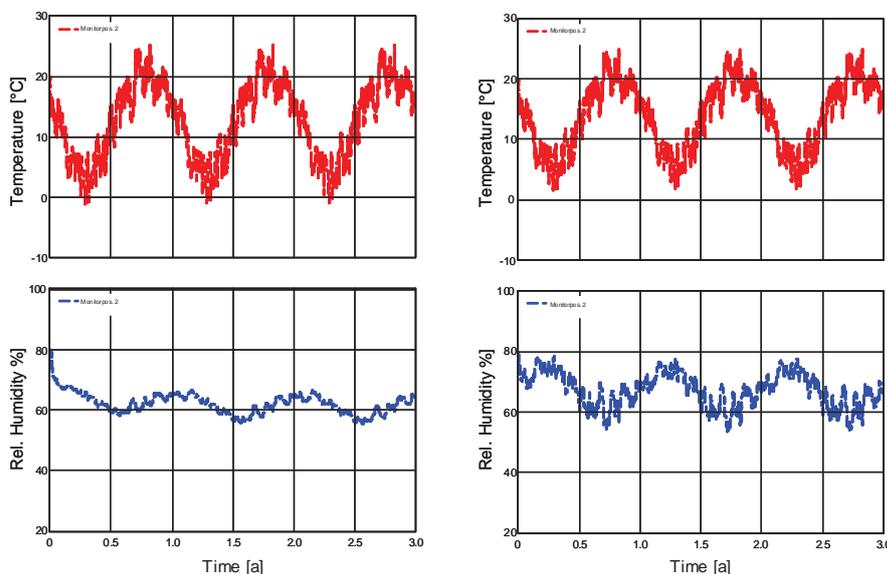


Fig. 7. Course of temperature (top) and relative humidity (bottom) between external wall and internal insulation with careful implementation (left) and without perfect tightness with back flow of 1 l/mh (right).

Since it cannot be suggested that this is always the case, the tolerance of the construction must be investigated. To find an answer to the question the following investigations were based on a defined leakage with a back flow of the insulation board by warm and humid air from the interior. The following calculations were based on a back flow of 1 liter per hour and running meter wall length. Fig. 7, right side, shows the situation behind the insulation. Due to the inflowing warm air minimum temperatures of barely below 0 °C are raised to scarcely above freezing temperature. The rel. humidity doesn't exceed 80 % despite the back-flow.

Fig. 8, left side, shows the result of a further increase of the back flow up to one cubic meter per day and running meter wall length. In winter, however, 80 % r. h. is temporarily exceeded so that mold growth could no longer be excluded. For verification the calculated course of temperature and relative humidity at this point is used for the mould growth prognosis program WUFI®-Bio. As the results in Fig. 8, right side, show the spore water content never exceeds the limit water content. Despite back flow no mould growth must be expected under these conditions. Therefore, the wall structure with this kind of internal insulation shows a considerable tolerance of untightness, one reason may be the relatively low thickness of the insulation material.

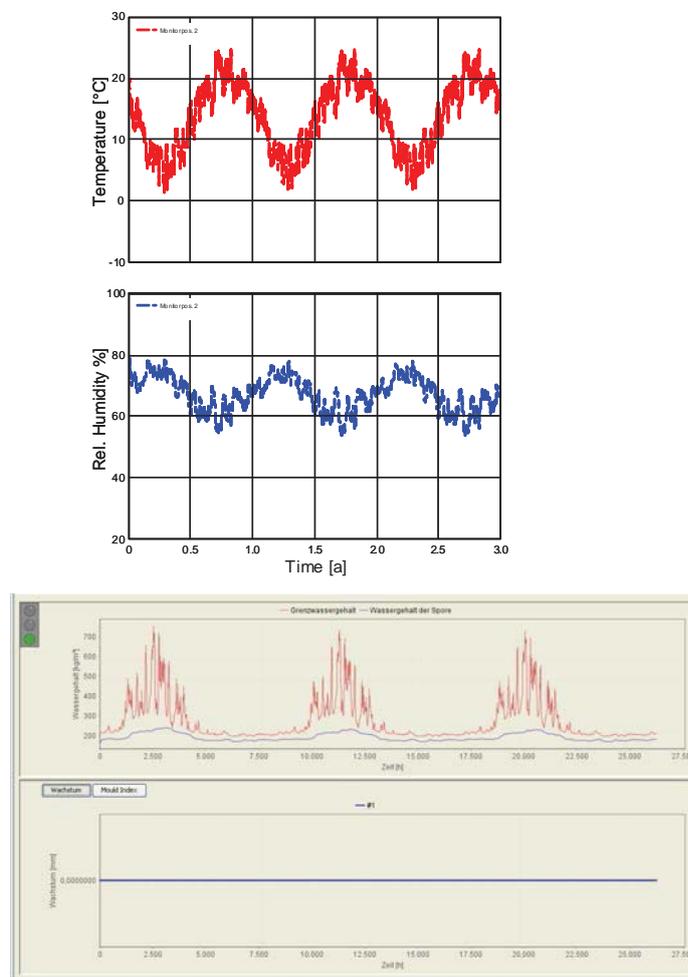


Fig. 8. Course of temperature (top) and relative humidity (bottom) between external wall and internal insulation at a back flow of 1 m³/md (left) and calculated results by WUFI®-Bio for the area behind the internal insulation.

4. Conclusions

A product has been developed by means of optimizations concerning the structure of the board and the material properties showing numerous positive characteristics. For the first time ever, a material is available showing a relatively high bearing capacity and simultaneously good insulation properties, which is manufactured from renewable material at low energy consumption and entails great advantages for the environment. Moreover, susceptibility to mould growth in practical application is relatively low, what is frequently a problem in case of renewable insulation materials. The material is sufficiently diffusion-open to support drying-out processes but diffusion-tight enough to work without any vapor barrier in many applications. Calculations of the internal insulation showed that at least in case of moderate thickness the typha boards can be directly doveled to the wall and coated by an internal plaster, and thus can function free of damage from the building physical point of view and have a considerable tolerance for errors in installation. The installation of the typha boards in the framework building in Nuremberg allowed the achievement of a thermal transmittance coefficient of approx. $0.35 \text{ W/m}^2\text{K}$ with a total thickness of the wall structure of only 20 cm including wall panel heating by a combination infilling with the typha board and internal wall surface area insulation. This result is extremely good for a framework building.

The measurements of temperatures and humidity in various depths of the structure carried out at the object during two heating periods prove the building physical suitability. In the beginning, slightly higher initial humidity occurred due to the built-in moisture added by internal and external plasters, and then the framework dried out rapidly and humidity remained low and uncritical. The measurements of the heat flow confirmed the positive results of the calculations. The measurements of the moisture contents of the timber also showed that due to the rapid drying-out only relatively low and uncritical moisture occurred in the timber. All in all, an extremely positive result is achieved from the building physical point of view and as concerns the preservation of historical monuments by the installation of magnesite-bound typha boards as insulation measure.

5. Acknowledgements

Thanks to Altstadtfreunde Nürnberg e.V. and to Deutsche Bundesstiftung Umwelt who have not only financially supported these investigations.

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