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Research paper

Risk of interstitial condensation in outer walls made of hemp-lime composite in Polish climatic conditions

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Abstract: The present paper presents results of a study on hemp-lime composite – a novel building material which is gaining attention thanks to its pro-ecological values, as well as interesting hygrothermal characteristics. The thermal conductivity and vapour permeability tests were performed on composites which varied in terms of composition and density as a result of use of various binders, different proportions of ingredients in a mixture and different compaction level during manufacturing with the use of the tamping method. The results obtained, indicating low thermal conductivity and very high vapor permeability, were tabulated with results of compressive strength obtained in the previous study on the same types of composites. The conclusions emphasise supreme importance of apparent density on properties of material, rather than binder composition – which exerts a significant effect only on compressive strength. The results of the performed tests were applied for determination of external walls' construction, which were subjected to analysis of risk of interstitial water vapor condensation according to Glaser method. For locations in all Polish climatic zones, no condensation or only a small amount thereof, in which case it does not accumulate in subsequent years, was found.

Keywords: hemp-lime composite, hempcrete, sustainable construction, thermal conductivity, vapor permeability, interstitial condensation

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1. Introduction

1.1. Hemp-lime composite – general characteristics

1.1.1. Components and structure of the composite

Hemp-lime composite, also known as "hempcrete" is a material obtained by mixing hemp shiv (mechanically treated *Cannabis Sativa L* stems), lime binder (most commonly a mix of binding substances with major share of hydrated lime) and water. Sand is an optional ingredient. *Cannabis Sativa L*, known as "industrial hemp" provides a source of fibers, nuts and shiv – raw materials used in numerous industries [1–4]. Until now, hemp shiv has been used as a biomass, animal bedding material or was otherwise considered a waste. The use of other plant products for production of lightweight concretes (e.g. wheat, barley, flax, kenaf, sunflower) has been investigated worldwide [2, 5, 6], but it was hemp that gained the widest application so far. Besides hydrated lime, binder most often contains natural hydraulic lime, cement, pozzolans and minor additives. The use of other binding substances has also been analyzed – especially gypsum [1], clay [7, 8], magnesium oxide [9, 10] and corn starch [7, 11]. Mass proportions of hemp shiv and binder (H:B) vary depending on the application of the material – from about 1:1 for light insulation in loose form, about 1:2 for wall mixes, to about 1:7 for hemp-lime plasters.

Hempcrete is characterised by high porosity – approx. 80% [12, 13] which determines the properties of the material to a great extent. Open and connected pores of various sizes can be found, including inter-particle pores and intra-particle pores of hemp shiv and binder [14, 15].

1.1.2. Mechanical properties

In the vast majority of cases, hemp-lime composites are not used as load-bearing materials, hence their mechanical strength should be only sufficient to carry its own loads. Compressive strength of hempcrete depends on the proportions of components in a mix (greater share of binder results in a greater strength [5, 12, 16, 17]) and compaction level associated with method of material application [18]). Other factors are: hemp shiv characteristics (larger share of shorter hemp particles results in a greater compressive strength [19, 20], but the strength gain may be slower [12]), binder characteristics (the presence of hydraulic binders in addition to hydrated lime results in a faster strength gain than in the case of pozzolan admixtures, however, in both cases similar values are noted in a longer term [21]), mixing procedure and curing conditions [22]. The flexural strength of hempcrete increases with density [5, 18], but the presence of fibers and longer hemp particles is also important [5]. The compressive and flexural strength values for typical applications reported in source literature usually range from 0.1 to 0.9 MPa and from 0.05 to 0.25 MPa respectively.

1.1.3. Thermal properties

The porous structure of the lime-hemp composite is decisive for its low thermal conductivity, which generally increases with the density of material [5, 16, 17, 23, 24] as an effect of change in the proportions of ingredients (the lower share of hemp shiv in the mixture results in a non-linear increase in thermal conductivity [5, 16]) and in greater compaction of the mix [5, 23]. Study of composites made with the use of selected shiv particles [19] did not show significant

differentiation in thermal conductivity of the material. In another study [20], composites with the use of smaller shiv particles were characterized by higher conductivity due to better compaction of the mix. On the other hand, according to [5], excessively large voids that result from the use of hemp shiv containing too large particles may lead to an increase in heat transfer by convection. In [24], it has been found that the thermal conductivity may decrease for the composite with greater content of hydraulic binders, although the difference was not significant. A similar, yet more explicit, trend was observed in [25]. Increase in thermal conductivity together with moisture content of composite was described in [13]. Thermal conductivity depends also on an arrangement of hemp particles within a partition being an effect of the manufacturing method applied – for composites with the same composition but a different tamping direction, the obtained λ values for heat flow across and along the dominant particles arrangement were 0.09 and 0.101 W/(m·K) respectively [5]. The thermal conductivity values reported in literature range from 0.07 to 0.15 W/(m·K) [5, 16, 17, 23, 24].

1.1.4. Hygric properties

Hemp-lime composite is characterised by high water vapor permeability. According to [5], the permeability of hempcrete is influenced by both: the characteristics of hemp shiv and binder, as well as by their proportions. Study [24] showed a negligible reduction in water vapor permeability of the composites that contain hydraulic binders, as compared to those with pozzolans. This suggests that, to a greater extent, permeability depends on macropores between shiv particles (influenced by the proportions of components and the degree of compaction), than micropores of binder. The use of fine shiv results in lower permeability [20]. Studies [14] indicate the impact of manufacturing method on vapor permeability of hempcrete, which is the highest for spraying and lowest for tamping method. The values of the diffusion resistance coefficient of hempcrete remain within the range from about 3.6 to 7.7 in 50% RH [26]; usually oscillate around 5 [5, 14, 24]. An increase in the water vapor permeability with the increase in relative humidity was noted, which results from the increase in macroscopic moisture transport [14].

Hempcrete is characterized by high water absorption rate – absorptivity by weight of composites of various types ranges from 89 to 148% and decreases with the material's density [5]. The material's capillary uptake depends on the type of binder and decreases with an increase in the content of hydraulic additives [24]. The prevalence of large pores increases the absorption during immersion, but the composite absorbs less water due to capillary action [5]. Hempcrete is highly hygroscopic. Water absorption from air increases steadily up to 60÷80% RH, then it rises sharply; sorption curves show strong hysteresis [14].

1.1.5. Fire-resistance and corrosion-resistance

Hemp shiv is flammable, however, its complete coverage with lime binder protects against ignition during the fire [2]. According to the declarations by French producers, the hemp-lime composite can be classified as a non-flammable or hardly flammable material [27]. Fire resistance test carried out by the British Building Research Establishment on fire-exposed hempcrete walls with centrally placed wooden structural posts, subjected to vertical load, showed resistance in terms of integrity, insulation and load-bearing capacity for 73 minutes [27].

High lime content provides alkaline environment which prevents biological corrosion of the material (unless its ability to diffuse water vapor is inhibited). Research consisting in the introduction of microorganisms found in the soil and air into the composite demonstrated the resistance of the material to biological corrosion [21].

1.1.6. Pro-ecological values

The impact of construction sector on the environment is significant: approx. 36% of global energy use and approx. 39% of GHG emissions comes from buildings [28]. For that reason, sustainable construction materials like e.g. raw earth [29] or bio-aggregate concretes [6] are investigated.

Hemp-lime composite is characterised by low embodied energy and low, zero or either negative carbon footprint, depending on the production method and on research methodology. Hemp binds CO_2 from the atmosphere in the photosynthesis process in the growth phase: dry hemp contains approx. 50% carbon [30], which means that 1 t sequestrates approx. 1.8 t of CO_2. The impact of hemp cultivation on the natural ecosystem is relatively low [4, 31–34]. The replacement of standard aggregate decreases the environmental costs and prevents degradation of the natural landscape. The binder is produced with a significant energy input and CO_2 emission related both: to the chemical reaction (conversion of $CaCO_3$ into CaO) and to the combustion of fossil fuels which provides the energy required for the technological production process. The produced composite binds CO_2 from the atmosphere (up to 76.8% released as a result of a chemical reaction within one year from its production [35]), thus reducing the total emission associated with the material. Hemp is a renewable resource, however the methods of disposal of the entire composite are not well recognised yet [36].

A comparison of 1 m^2 of a 0.26 m thick wall made of hemp-lime composite with an identical element made of aerated concrete showed energy expenditure of 370–394 MJ and sequestration of 14–35 kg of CO_2 (in 100 years) and energy expenditure of 560 MJ and emission of 52.3 kg of CO_2 respectively [37]. Comprehensive cradle to grave assessment [38] determined the composite's carbon footprint for various scenarios of production and use as from –90 to 30 kg CO_2/m^3 compared to 126 kg CO_2/m^3 for EPS and 167 kg CO_2/m^3 for mineral wool.

1.2. Application in construction

The first applications of hemp-lime composite were observed in renovations of historical wattle and daub buildings in France, since 1986. The corroded infill of timber frame buildings (mostly earth mixed with organic fibers) was experimentally replaced with a mix of hemp and lime, as use of cement only worsened the condition of such buildings in previously performed works [1]. The application of this solution stopped the decay of the corroded matter, helped to dry up the wood, left the wall open to diffusion of water vapor and improved energy performance of the buildings, allowing the preservation of historic architecture. Success of works led to development of technology – it became more widely used for renovations of historic timber-frame, as well as masonry buildings. In the 1990s, the composite became popular as a material solution for single family housing. Nowadays, its application in construction of residential, industrial, utility and other buildings can be increasingly noticed, especially in France and

the UK, but also other countries [1–3]. Improvement of technology provided better quality of hemp shiv, specially designed binders and new methods of application, besides the manual tamping method. These include spraying, prefabrication of bricks, blocks and of entire wall segments [1–3]. The composite is mostly used as filling for walls with timber structural frame, but also for horizontal thermal insulation layers (low density mixes), vertical insulation layers of existing walls and insulation of floor on ground (high density mixes) [1–3].

2. Laboratory tests

2.1. Materials and samples preparation

Three types of mixes were designed for the tests (Table 1). For each of them, the same "Białobrzeskie" hemp shiv produced in northern-east Poland in 2016 was used, with no declared technical properties. Measured thermal conductivity of the shiv was 0.046 W/(m·K) for the bulk density of 92 kg/m^3 [39]. The first mix (marked as T) contains "Tradical PF70" commercial binder, intended specifically for the production of lime-hemp composite, commonly used for this purpose in the EU countries. Its declared composition is: 75% – hydrated lime, 15% – hydraulic ingredients, 10% – pozzolans, approx. 0.5% – additives. In the second mix (marked as B), the commercial binder was replaced with a mixture of binding substances: 75% – hydrated lime CL-90-S (according to EN 459-1), 15% – hydraulic lime HL5 (EN 459-1), 10% – portland cement CEMII/B-V 42.5 N (according to EN 197-1). Substances widely available in the country were used, as the local origin of the ingredients is essential to keep low carbon footprint of the material. The proposed substitute binder was not designed in order to optimize the properties of the material – its composition was determined on the basis of widely observed construction practice. The third mix (marked as TL) contains the same ingredients as T, but in different proportions (a lower share of binder). Water used for mixtures at a temperature of 20°C ±2°C came from the Warsaw water supply network.

Table 1. Composition of mixtures prepared for the tests

Mix symbol	Hemp shiv	Binder	Proportions by weight (Hemp : Binder : Water)
T	"Białobrzeskie"	Commercial	1 : 2 : 2.9
B	"Białobrzeskie"	Substitute	1 : 2 : 3.1
TL	"Białobrzeskie"	Commercial	1 : 1.5 : 2.18

The mixing order and conditions during maturation were determined on the basis of preliminary tests (discussed in [22]). Measured amounts of ingredients of each mixture were combined in accordance with the assumed proportions, with the use of a mixer with a vertical rotation axis. At first, the binder was mixed with water (for approx. 2–3 min.), then the hemp shiv was dosed and the whole was mixed for another 5–6 minutes until the consistency of the mixture became homogenous.

Rectangular 0.3 × 0.3 × 0.08 m samples and cylindrical samples with the diameter of 0.128 m and the height of 0.1 m were immediately made of each mix by manual tamping with a wooden hammer (weighing approx. 1 kg) in plywood and metal molds. Large samples were tamped in 0.1 m layers and kneaded by hand at the edges. The desired initial density of samples was achieved by placing the appropriate amount of the mix in a mold of a given volume and applying appropriate degree of compaction. Initial density of the T samples was differentiated – 3 densities were achieved: 750 kg/m^3 (maximum possible compaction), 650 kg/m^3 and 550 kg/m^3 (minimum compaction which ensured samples integrity). For the B samples, the density of 650 kg/m^3 was set, while for TL – 550 kg/m^3 – the maximum possible density to be achieved by the manual tamping method, due to the greater share of the shiv in that mix. The molds were opened after 1–2 hours and the samples were moved to a climatic chamber (temperature 18°C ±2°C; RH 75% ± 10%) for a period of 28 days. For the remaining period, the samples were stored at temperature 23°C ±2°C and RH 50% ± 10%. Previously conducted tests [39] on cubic 0.1 × 0.1 × 0.1 m samples with the use of the same materials and procedure showed satisfactory compressive strength of the material and confirmed its suitability for use in external walls with a separate load-bearing frame (Fig. 1).

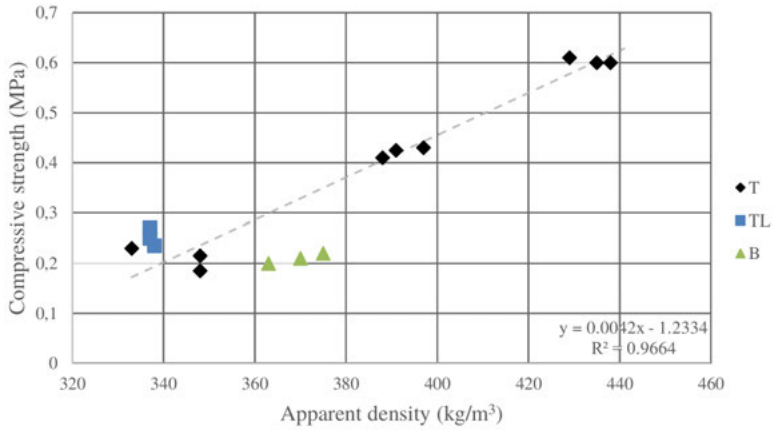

Fig. 1. Results of compressive strength tests of T, B and TL samples 90 days from manufacturing

2.2. Test methods

2.2.1. Thermal conductivity

The thermal conductivity tests were carried out 3 months after sample production, using FOX 314 plate apparatus, with heat flux density sensors on 5 samples (Fig. 2) according to the EN 12664:2002 [40]. Before the testing the mass of the samples was stabilized. The conditions in the room were stable (temperature 22.2–22.7°C). The measurements were made at an average sample temperature of 10°C, a temperature difference across the sample thickness of 20 K, heat movement from the bottom to the top. The relative mass change during the test didn't exceed 0.2%.

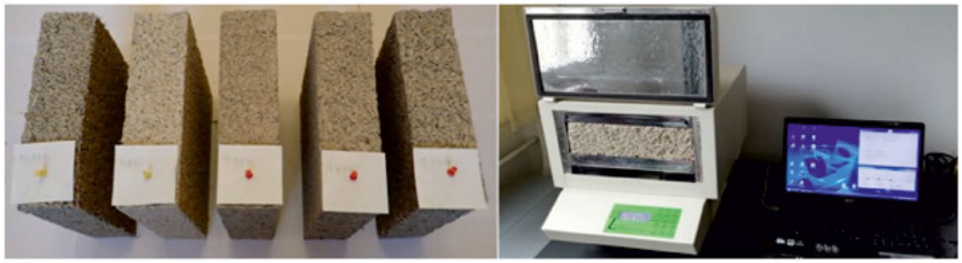

Fig. 2. Samples for thermal conductivity tests (left); FOX 314 plate apparatus (right)

2.2.2. Vapor permeability

The vapor permeability tests were conducted in accordance with the EN ISO 12572:2016 [41] on 15 samples six months after their production. The mass of the samples was stabilized. All samples were placed in steel vessels. The lower part of each vessel was filled with calcium chloride, a highly hygroscopic substance used in such tests, to produce RH 0%. In the upper part of the vessel, a sample was placed and sealed with liquid wax. The vessels were weighed and placed in a chamber that ensured constant conditions: temperature 23°C ±1°C and RH 50% ± 5% (Fig. 3). All vessels were weighed at intervals of 2 or 3 days until the calculated change in weight, per hour, for each individual container in each of the previous 5 measurements was within 5% of the mean change in weight of the container from these measurements. The test was completed after 19 days. The coefficient of water vapor permeability of the material in isothermal conditions was calculated using the following formula:

$$\delta = (G \cdot d)/(A \cdot \Delta p \cdot n) \tag{2.1}$$

where: G – hourly mean weight change of the sample from the last 5 consecutive measurements (g/h), d – sample height (m); A – exposed surface area of the sample (m^2); Δp – water vapor pressure gradient (Pa); n – correction factor due to the difference between the exposed surface area of the sample (A) and the actual cross-sectional area of the sample – calculated in accordance with Annex F of the EN ISO 12572:2016 [41].

The coefficient of diffusion resistance was calculated according to the following formula:

$$\mu = \delta_a/\delta \tag{2.2}$$

where: δ_a – coefficient of water vapor permeability of air (assumed value: $720 \cdot 10^{-6}$) (g/(m·h·Pa)).

Fig. 3. Exemplary vessels with samples sealed (left); chamber providing constant conditions (right)

2.3. Results and discussion

The results of the thermal conductivity test showed values ranging from 0.090 to 0.113 W/(m·K). Measurement uncertainty for the method used equalled 3%. As predicted, thermal conductivity rises with apparent density of the composite (Fig. 4). More tests of the same composites – on 15 samples and in varied relative humidity conditions were presented in [39]. The results obtained are generally consistent with literature data [5, 16, 17, 23–25].

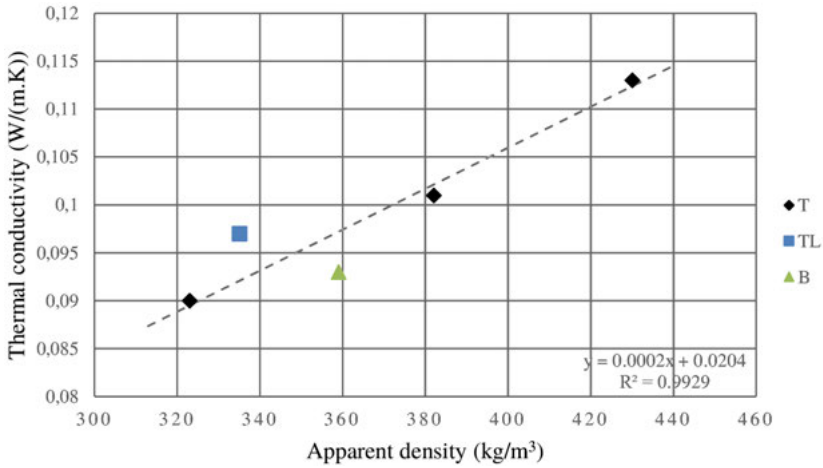

Fig. 4. Results of thermal conductivity tests of T, B and TL samples 90 days from manufacturing

The conducted tests confirmed a very high water vapor permeability, and thus a low water vapor diffusion resistance factor of the composite – within the range from 2.80 to 4.73 (Fig. 5).

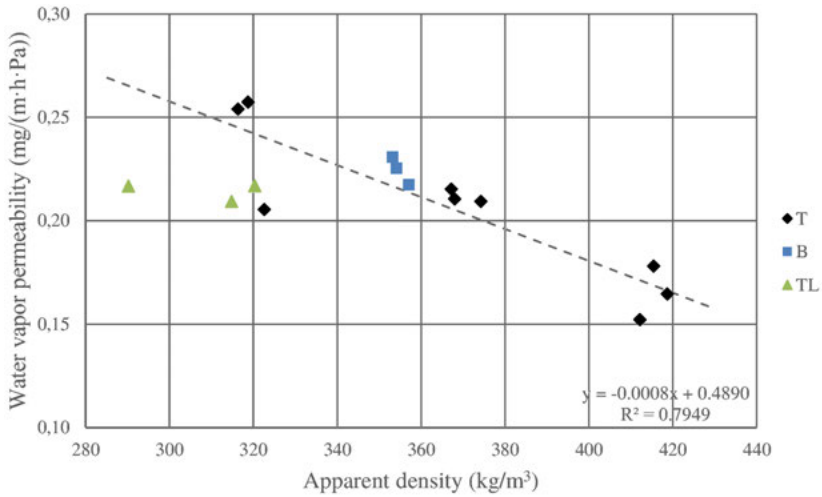

Fig. 5. Results of vapor permeability tests of T, B and TL samples 6 months from manufacturing

Measurement uncertainty for testing method was 3%. The recorded values of μ are similar or slightly lower than those referred to in [5, 14, 25, 26], which may have been caused by the lower apparent density of the tested composite. A decrease in vapor permeability of the T samples was observed along with the material density resulting from a modified degree of compaction. The water vapor permeability of the composite produced with application of substitute binder (B) is similar to that fabricated with the special binder (T) – both binders contain 75% hydrated lime; the differences in the remaining binder didn't noticeably affect the vapor permeability of the material. Samples with a density of 550 kg/m^3 and a lower binder content (TL) are less permeable than the T samples with the same density and a greater binder content but lower compaction, which indicates a greater importance of macropores for the ability of material to transport water vapor.

Comparison of the conducted tests results with previous studies of compressive strength (Fig. 1) shows crucial importance of apparent density on basic properties of the material. The binder composition exerts a significant effect only on compressive strength, while for thermal conductivity and vapor permeability it remains inconsiderable. Composite with greater share of shiv and a more compact structure (TL) showed a slightly higher strength, thermal conductivity and water vapor diffusion resistance, as compared to relationship with density obtained for T samples. This indicates the importance of pores structure in addition to density.

3. Analysis of interstitial condensation

3.1. Construction of partitions

Two types of walls were designed for the purpose of the analysis, both with the thermal transmittance U = 0.2 W/(m^2·K), compliant with the applicable requirements for external walls in residential buildings in Poland [42] (Fig. 6). Properties of the materials used are listed in the Table 2.

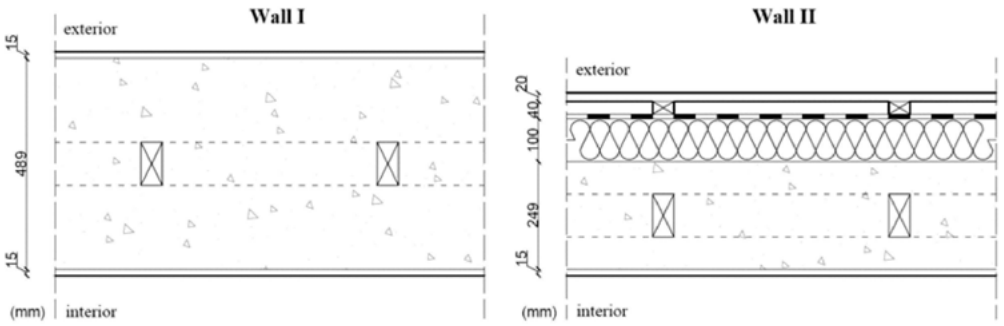

Fig. 6. Construction of walls I and II designed for analysis of interstitial condensation

The U-value was calculated in accordance with EN ISO 6946:2017-10 [46]. The first wall (marked as I) consists of hemp-lime composite of a thickness 0.489 m, with centrally placed

Table 2. Characteristics of the materials used in the analysed walls

	Apparent density (kg/m^3)	Thermal conductivity λ (W/(m·K))	Water vapor diffusion resistance factor μ (–)	Source of data
Wood (pine)	625	0.16	–	PN-EN ISO 10456: 2009 [43]
T650	382	0.101	3.7*	Present study * – interpolated
Mineral wool	–	0.035	1	Technical document [44]
Lime plaster	1600	0.8	10	PN-EN ISO 10456: 2009 [43]
Clay plaster	1800	0.91	8	Literature [45]

vertical posts (0.05 × 0.1 m, distanced every 0.5 m) and 0.015 m thick plasters: clay plaster on the inner side and lime plaster on the outer side. The second wall (marked as II) consists of (starting from the inside): clay plaster (0.015 m), hemp-lime composite T650 (0.249 m), mineral wool (0.1 m), fully-ventilated air cavity (0.04 m), one-direction vapor-permeable windproof membrane (diffusion equivalent thickness Sd = 0.02 m) and wooden (pine) cladding (0.02 m).

3.2. Calculation method

The risk of interstitial condensation was assessed according to the EN ISO 13788:2012 [47]. The method assumes that the transfer of moisture in the partition takes place only by diffusion of vapor and depends on the ratio of the pressure difference between the internal and external environment, as well as diffusion resistance of the partition, assuming constant vapor permeability of air. The method fails to take into account the hygroscopicity of materials, nor does it account for: sorption dampening, changes in the properties of materials due to their moisture content, transport of moisture in a liquid phase inside the materials, effects of latent heat and air movement through gaps or inside air cavities. The method assumes constant boundary conditions within a month and one-direction transport of moisture. The analysis was performed for 6 selected locations, one from each of climatic zones I–IV and 2 from climatic zones V – average monthly temperatures and relative air humidity are given in Table 3. The internal conditions were adopted as for residential buildings: air temperature 20°C and real pressure corresponding to internal moisture load (3rd class according to EN ISO 13788:2012 [47]). For the purpose of the analysis, homogeneity of the layers of the considered partitions (no wooden frame) was assumed. The analysis was performed for each month.

Table 3. Average monthly temperatures and relative air humidity in the selected locations

Location / month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Kołobrzeg (zone I)	θ_e (°C)	0.7	2.6	4.3	5.0	11.9	13.9	15.7	16.5	13.3	8.0	5.9	2.5
	φ_e (%)	85	84	84	79	75	80	79	78	80	82	84	86
Poznań (zone II)	θ_e (°C)	0.2	–1.8	2.7	8.3	13.0	16.8	18.3	18.4	13.5	7.0	2.2	–0.1
	φ_e (%)	84	83	77	68	65	71	73	74	81	84	88	89
Warszawa (zone III)	θ_e (°C)	–1.2	–0.9	4.4	6.3	12.2	17.1	19.2	16.6	12.8	8.2	2.9	0.8
	φ_e (%)	86	83	78	72	69	74	74	76	81	85	87	89
Olsztyn (zone IV)	θ_e (°C)	–3.6	–2.9	2.5	5.5	10.9	15.4	17.7	16.5	12.8	6.3	1.9	–0.5
	φ_e (%)	89	84	81	77	72	77	78	76	82	85	90	91
Suwałki (zone V)	θ_e (°C)	–5.3	–4.9	1,3	6.8	13.6	15.7	16.1	15.6	12.4	6.8	0,1	–2.3
	φ_e (%)	90	88	84	76	71	77	79	76	82	87	91	90
Zakopane (zone V)	θ_e (°C)	–2.8	–2.3	1.1	5.0	9.8	12.7	14.3	13.1	11.2	4.6	1.5	–3.0
	φ_e (%)	82	78	77	73	78	76	80	80	83	81	81	82

3.3. Results and discussion

The analysis of wall I for: Kołobrzeg (zone I), Poznań (zone II), Warszawa (zone III) and Zakopane (zone V) showed no risk of interstitial condensation. For Olsztyn (zone IV) condensation takes place in December and January (0.06 kg/m^2 in total) on the depth located within the zone of freezing, while the condensate evaporates completely by March. For the Suwałki location (zone V), condensation occurs in December, January and February (0.25 kg/m^2) and reaches deeper into the composite (also freezing zone) (Fig. 7), but by April all moisture evaporates from the partition. The partition meets the legal requirements, provided that the moisture does not lead to its degradation. As condensation takes place in the freezing zone, the frost resistance of the material is important. Such studies were discussed in [21] and indicate sufficient frost resistance of the composite.

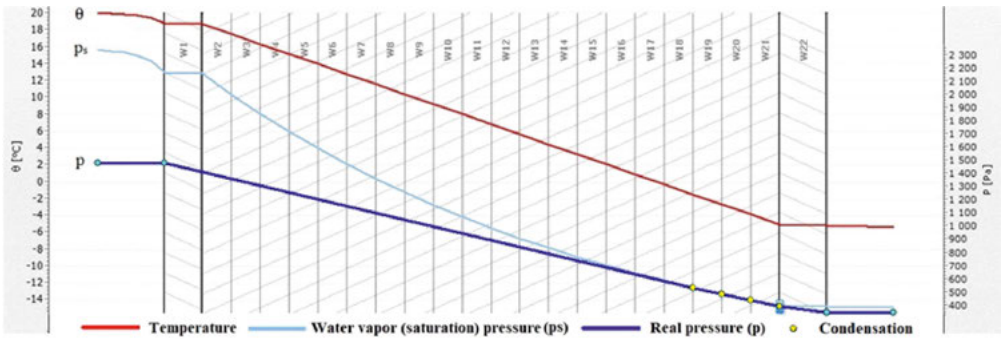

Fig. 7. Diagram of temperature distribution, real and saturation pressure of wall I in Suwałki, in January

Analysis of the wall II showed no risk of interstitial condensation in any of the considered locations. Diagram for Suwałki is presented in Fig. 8. By increasing the S_d value of the membrane, the limit value for which condensation appears for this location was determined at Sd $\geq$ 0.1 m. This means that lime plaster with a thickness of up to 0.01 m can also be used to replace the foil. The ventilated air gap is necessary as for tightly arranged wooden cladding with a thickness of 0.02 m $S_d \geq 0.4$ m.

For slightly different properties of materials or assumed conditions, the results of condensation analysis may be more or less favorable (e.g., for a composite which $\mu \geq 4.4$, condensation does not occur in any case). The results obtained according to EN ISO 13788:2012 [47] may be less reliable for structures with high heat and moisture capacity, and for those that have been subjected to significant air leakage. Hempcrete is characterized by high moisture capacity [26], therefore subsequent detailed analyzes should be based on models that take into account complex physical phenomena related to the transport of moisture within the material.

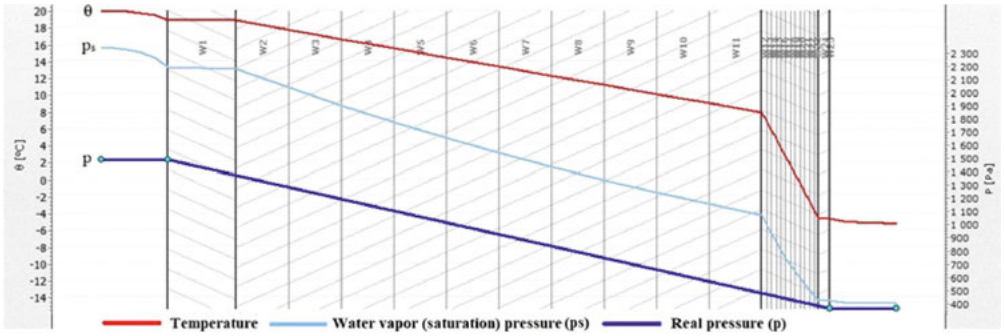

Fig. 8. Diagram of temperature distribution, real and saturation pressure of wall II in Suwałki, in January

4. Conclusions

Hemp-lime composite is characterized by a low thermal conductivity and high water vapor permeability. Apparent density, which results either from proportions of components or compaction level of a composite, is a feature of greatest importance on material's properties. Analysis according to Glaser method showed construction possibility of outer walls in Polish climatic conditions. Nevertheless, prior to construction, a detailed analysis should be performed for specific locations and construction arrangements. The use of open-to-diffusion walls made of a natural material can lead to healthier living conditions and development of more sustainable construction.

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Ryzyko kondensacji wgłębnej w ścianach zewnętrznych wykonanych z kompozytu wapienno-konopnego w polskich warunkach klimatycznych

Słowa kluczowe: kompozyt wapienno-konopny, hempcrete, budownictwo zrównoważone, przewodność cieplna, paroprzepuszczalność, kondensacja wgłębna

Streszczenie:

W artykule przedstawiono wyniki badań kompozytów konopno-wapiennych (*hempcrete*) – nowego materiału budowlanego, który zyskuje zainteresowanie dzięki swoim zaletom proekologicznym (niska energia wbudowana i ślad węglowy) oraz ciekawym właściwościom cieplno-wilgotnościowym. *Hempcrete* jest wytwarzany poprzez zmieszanie paździerza konopnego (łodygi rośliny *Cannabus Sativa L* poddanej obróbce mechanicznej), spoiwa wapiennego (najczęściej mieszaniny różnych spoiw o największym udziale wapna hydratyzowanego) oraz wody. Źródła literaturowe wskazują, że materiałcharakteryzuje się niewielką wytrzymałością na ściskanie (w zakresie 0,1÷0,9 MPa), niskim przewodnictwem cieplnym (0,07÷0,14 W/(m·K)) i niewielkim oporem dyfuzyjnym (μ = ok. 5). Podstawowym zastosowaniem materiału jest wypełnienie ścian o drewnianym szkielecie nośnym. Stosuje się także mieszanki o mniejszym udziale spoiwa do wykonywania poziomych warstw izolacji termicznej oraz o większym udziale spoiwa do warstw izolacyjnych w podłodze na gruncie, a także mieszanki tynkarskie.

Badania wykonano na kompozytach różniących się składem i gęstością w wyniku zastosowania różnego spoiwa (spoiwa specjalnego i jego zamiennika z ogólnodostępnych substancji wiążących), różnych proporcji składników w mieszance (większy i mniejszy udział spoiwa) oraz zróżnicowanego stopnia zagęszczenia podczas wytwarzania metodą ubijania. Wyniki wskazującą na współczynnik przewodzenia ciepła (określony wg EN 12664:2002) w zakresie 0,09÷0,13 W/(m·K) dla gęstości 323÷430 kg/m^3 oraz bardzo mały współczynnik oporu dyfuzyjnego (określony wg EN ISO 12572:2016) – w zakresie 2,8÷4,7 dla gęstości 308÷415 kg/m^3. Otrzymane wyniki podkreślają nadrzędne znaczenie gęstości objętościowej dla właściwości materiału; rodzaj spoiwa ma istotny wpływ jedynie na wytrzymałość na ściskanie, lecz niewielkie znaczenie dla wartości λ i μ w badanych zakresach. Zauważalne jest także znaczenie porowatości – kompozyt o bardziej zwartej strukturze charakteryzują wyższe wartości λ i μ niż kompozyt mniej zwarty o tej samej gęstości objętościowej.

Wyniki badań laboratoryjnych posłużyły do określenia konstrukcji dwóch ścian zewnętrznych o współczynniku przenikania ciepła równym 0,2 W/(m^2·K), które następnie poddano analizie ryzyka wgłębnej kondensacji pary wodnej dla 6 lokalizacji w Polsce należących do stref klimatycznych I–V. Analiza metodą Glasera wg EN ISO 13788:2012 wykazała niewielką ilość kondensacji w ścianie jednowarstwowej (wykończonej tynkiem glinianym od wewnątrz i tynkiem wapiennym od zewnątrz) w 2 lokalizacjach: Olsztyn (strefa IV) i Suwałki (strefa V), niemniej obliczono, że cały kondensat odparowuje w okresie wiosenno-letnim, a także brak kondensacji w ścianie warstwowej z pustką powietrzną w każdej z analizowanych lokalizacji. Wyniki wskazują na możliwość spełnienia wymagań przepisowych zawartych w „Warunkach Technicznych", aczkolwiek konieczne są dalsze badania nad trwałością przegród oraz analiza kondensacji z zastosowaniem modeli fizycznych uwzględniających dużą pojemność wilgotnościową materiału.

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