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MOISTURE VARIABILITY IN HEMP FIBER THERMAL INSULATION LAYER UNDER ENVIRONMENTAL CONDITIONS IN ROMANIA: AN ASSESSMENT

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Abstract. Conducting a comprehensive investigation into the behaviour of thermal insulation materials during the developmental phase is crucial for the production of materials. An indispensable aspect of this investigation is the evaluation of water content variation within the thermal insulation layer of various element configurations. Moisture has a considerable impact on the thermal conductivity of materials, which further highlights the significance of this assessment. The article evaluates the water content variability in hemp fibre heat insulation layer in Romania's distinct environmental conditions via ten-year hygrothermal simulations using specialized software. The results indicate a significant difference in the maximum water content within the thermal insulation layer across various climatic zones. On the other hand, the analysis suggests a relatively lower variability in water content when the element is exposed to different cardinal points. This study reinforces the importance of understanding how thermal insulation materials behave and examining water content variation within building elements, especially the insulation layer. Moreover, the evaluation of the likelihood of mould development is an essential measure that cannot be overlooked.

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Keywords: building energy performance; thermal resistance; hemp insulation; water content in the insulation layer.

1. Introduction

The fact that the energy consumption generated by the use of buildings is high, with a significant impact on global warming is something that is widely presented by the scientific community. Research findings on the state of energy consumption in the European Union, the United States, and China reveal the prevalence of excessive consumption levels, highlighting the potential and significance of reducing energy consumption (Xiaodong et al., 2016, D'Agostino et al., 2018, Beradi, 2017, Santamouris et al. 2021).

The most common and effective solution to reduce the energy consumption generated by the use of buildings is to use insulation materials which improve the thermal resistance of building elements. Considering this, there is a huge current effort in the development of new high-performance insulation materials. Given the growing concern about embodied energy and carbon in building insulation materials (Grazieschi et al., 2021, Kunič, 2017, recent studies have focused on the use of natural materials as effective insulation products. As a result, there is an increased interest in investigating innovative ways of harnessing the thermal insulation properties of natural materials, such as vegetable fibres, to create sustainable and environmentally friendly insulation options for buildings. Presently, natural insulation options such as cork (Lakreb et al., 2023, Fu et al., 2020), wool (Altin et al., 2022, Ghermezgoli et al., 2021), and hemp (Charai et al., 2021, Constantine et al., 2018) have gained widespread utilization across various regions of the globe. These materials have gained popularity due to their perceived eco-friendliness and potential to reduce the overall environmental impact of building insulation, while simultaneously providing adequate thermal resistance.

Thermal conductivity, which measures the ability of a material to transfer heat, is a crucial metric that characterizes the performance of thermal insulation materials. This property is subject to several factors, including temperature, humidity, and the ageing of the insulation material. Therefore, a comprehensive understanding of the factors that affect the thermal conductivity of insulation materials is imperative for assessing their effectiveness in thermal insulation applications.

Numerous authors (Khoukhi et al., 2019, Khoukhi, 2018, Beradi et al., 2017, Cai et al., 2017) have investigated the impact of temperature, humidity, and their interactive effects on the thermal conductivity of materials, as this is a topic of great significance in light of the critical role of thermal conductivity in the energy performance of buildings. Thus, this area of research has garnered widespread interest in the academic community.

In addition to the current state of the art, the article presents an assessment of the variation in the water content in the heat insulation layer made of hemp fibres in specific environmental conditions in Romania. To this end, numerical simulations were conducted using specialized software for hygrothermal analysis. The study focused on a wall-type component, which was insulated with a layer of material composed of 90% hemp fibre and 10% bi-component polyester fibre. The analysis covered ten years and took into account the specific environmental conditions in the five climate zones of Romania. The methodology, calculation program, presentation of the experimental study, and results are comprehensively described in the subsequent sections.

2. Material and Method

The material utilized for the simulation is a non-woven substance that is specifically designed for use as a thermal insulation material in construction applications. It consists of 90% hemp fibre and 10% bi-component polyester fibre, was produced through a carding-folding process and was further reinforced with bi-component fibres through heat treatment. It is worth noting that the thickness of the sample after heat treatment was measured to be 8.20 cm, indicating a contraction of 37% from the original size of 13.00 cm. This contraction was primarily attributed to the polyester fibres. Figure 1 shows the obtained material.



Fig. 1 – Heat-insulating non-woven fabric made of hemp and bi-component fibre.

The determined density of the material is 35,00 kg/m³. Also, characteristics specific to the insulation materials were measured. The material's thermal conductivity determined as a mean of three is 0.0554 W/mK and the volumetric heat capacity is 0.0890 MJ/m³K.

Numerical simulations were carried out to evaluate the variation in water content within the thermal insulation layer composed of the before-mentioned material. The analysis was performed in compliance with EN 15026:2007, a standard that governs the hygrothermal performance of building components and building elements. To conduct hygrothermal analyses, a specialized calculation program named WUFI® Pro (*WUFI® Pro* | *WUFI (En)*)

was utilized, a software widely used by various researchers (Cascionea et al., 2017, Brambilla et al., 2020, Lee et al., 2020, Zeng et al., 2023) in performing hygrothermal analyses. Heat and mass transfer for a wall-type construction element was analysed. The risk of mould growth has also been evaluated with WUFI® Bio software (*WUFI® Bio* | *WUFI (en)*). The structure of the analysed element is shown in Figure 2.

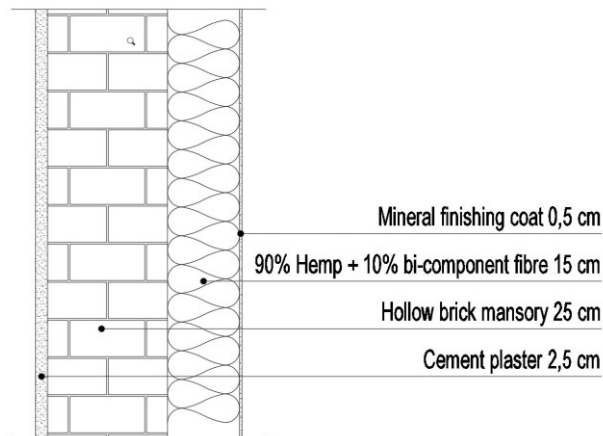


Fig. 2 – Structure of the analyzed element.

To tailor the conducted analyses to the climate of Romania, the outdoor climatic conditions were set and multiple sets of climate data from all five climatic zones in Romania were utilized. A city-specific climate data set was selected for each climate zone, which included Constanta for climate zone I, Bucharest for climate zone II, Iasi for climate zone III, Suceava for climate zone IV, and Miercurea Ciuc for climate zone V. The climatic data used were the typical climatic year and hourly climatic data. The indoor climate was established in compliance with the guidelines stipulated by EN 15026:2007, taking into account the fluctuations in indoor temperature and relative humidity.

The research investigated the effects of environmental factors, including exposure to solar radiation, wind, and precipitation, on thermal and mass transfer in wall elements. The study analysed different orientations, such as North, East, South, and West, for each climatic zone to determine the extent of their influence on transfer processes.

3. Results

Following an examination of a building element in terms of heat and mass transfer, the WUFI® Pro (*WUFI® Pro* | *WUFI (En)*) software generates results concerning variations in water content at both the component layer and

the overall element level. The total water content variation of an analysed element is presented in Figure 3. The element in question is exposed to the North and is specific to the climate conditions of Bucharest.

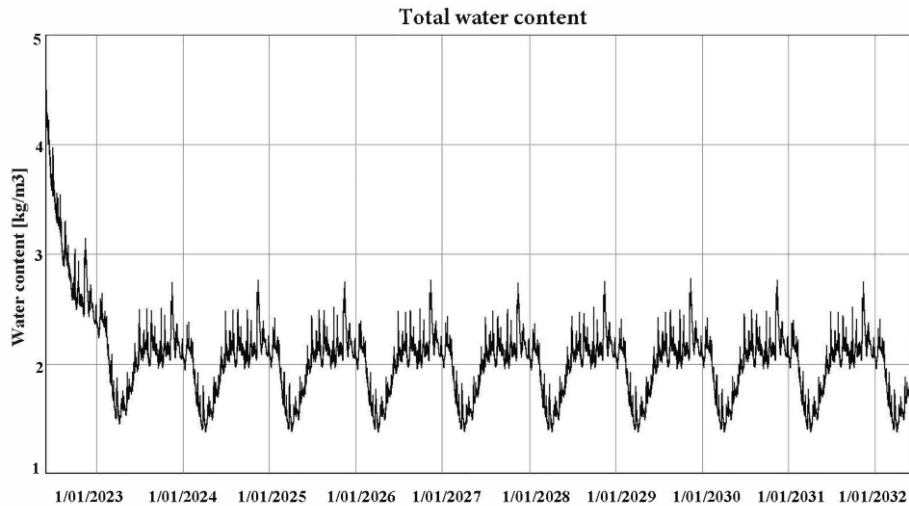


Fig. 3 – Variation of the total water content of the building element.

Figure 4 displays the variation in water content within one of the component layers, specifically the insulating layer comprised of 90% natural hemp fibres and 10% two-component fibres.

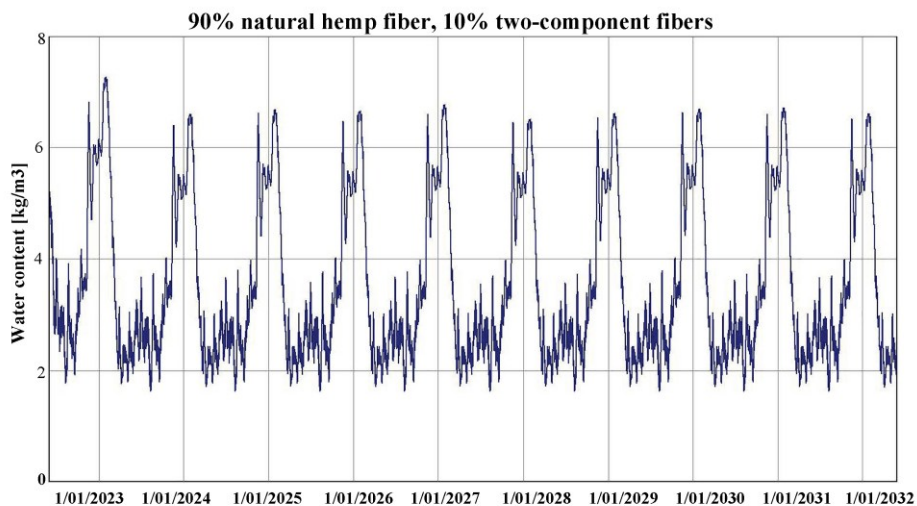


Fig. 4 – Variation of the water content in the insulation layer.

A comprehensive summary of the results obtained from all analysed cases will be provided below in Table 1. This will encompass details about the water content of the insulation layer made from natural hemp fibres. The summary will include the minimum and maximum values, as well as the values observed at the start and the end of the analysis.

Table 1
Summary of the results

Climatic zone	Orientation	Water content – insulation material [kg/m ³]			
		Start	End	Min.	Max.
<i>I</i> (Constanta)	<i>N</i>	5.33	3.14	1.97	5.50
	<i>E</i>		3.14	1.97	5.42
	<i>S</i>		3.17	1.97	5.42
	<i>V</i>		3.17	1.97	5.42
<i>II</i> (Bucharest)	<i>N</i>		2.10	1.63	7.27
	<i>E</i>		2.12	1.62	7.61
	<i>S</i>		2.09	1.61	6.44
	<i>V</i>		2.09	1.61	6.32
<i>III</i> (Iasi)	<i>N</i>		3.11	1.53	6.43
	<i>E</i>		3.15	1.55	6.26
	<i>S</i>		3.24	1.54	6.36
	<i>V</i>		3.19	1.54	6.70
<i>IV</i> (Suceava)	<i>N</i>		3.94	1.90	6.30
	<i>E</i>		3.93	1.88	5.96
	<i>S</i>		3.93	1.88	5.95
	<i>V</i>		3.94	1.90	6.31
<i>V</i> (Miercurea Ciuc)	<i>N</i>		2.36	2.11	8.31
	<i>E</i>		2.31	2.07	7.94
	<i>S</i>		2.32	2.11	8.60
	<i>V</i>		2.36	2.13	9.00

Simulation experiments were conducted to assess the growth of mould in wall-type construction elements under the diverse climatic conditions outlined earlier. None of the twenty scenarios yielded spore water content levels exceeding the critical threshold, indicating a lack of mould-growing risk. Figure 5 presents the variation of critical water content and the variation of the water content of spores for the same element exposed to the North and to specific climatic conditions of Bucharest.

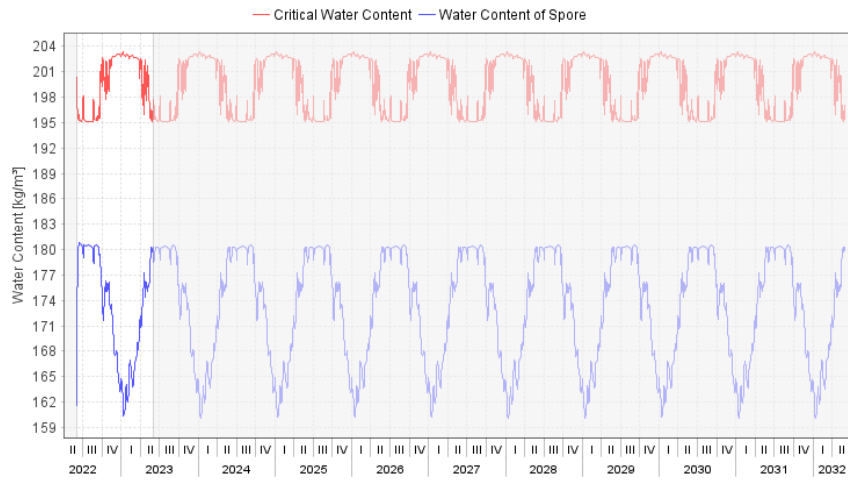


Fig. 5 – Variation of the water content in the insulation layer.

4. Discussion

To enhance comprehension of the fluctuation of moisture content within the thermal insulation layer, the outputs obtained from simulations underwent processing, and two distinct forms of analysis were conducted.

The initial form of analysis aimed to underscore dissimilarities in the upper limit of moisture content among distinct cardinal directions for the same climatic zone. The variation of the maximum water content in the thermal insulation layer, in this case, is shown in Figure 6.

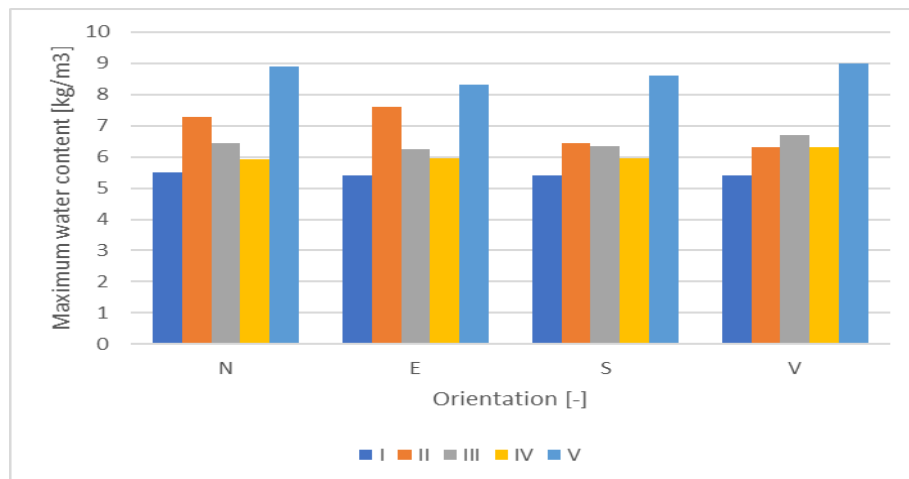


Fig. 6 – Graphic representation of maximum water content – same climatic zone.

Through an examination of the deviation in the highest degree of water content in the thermal insulation layer under identical climatic circumstances related to a particular climatic zone and with distinct exposure to the cardinal points, it is discernible that the percentage variation is relatively minor. Except for climate zone II, where the maximum percentage divergence between values amounts to 18.52%, in the case of the remaining climatic zones, the maximum percentage discrepancy is calculated to be 7.97%.

The second mode of analysis intended to accentuate the distinctions in the uppermost limit of moisture content, concerning different climatic zones, but with the same orientation. The variation of the maximum water content in the thermal insulation layer, in this case, is shown in Figure 7.

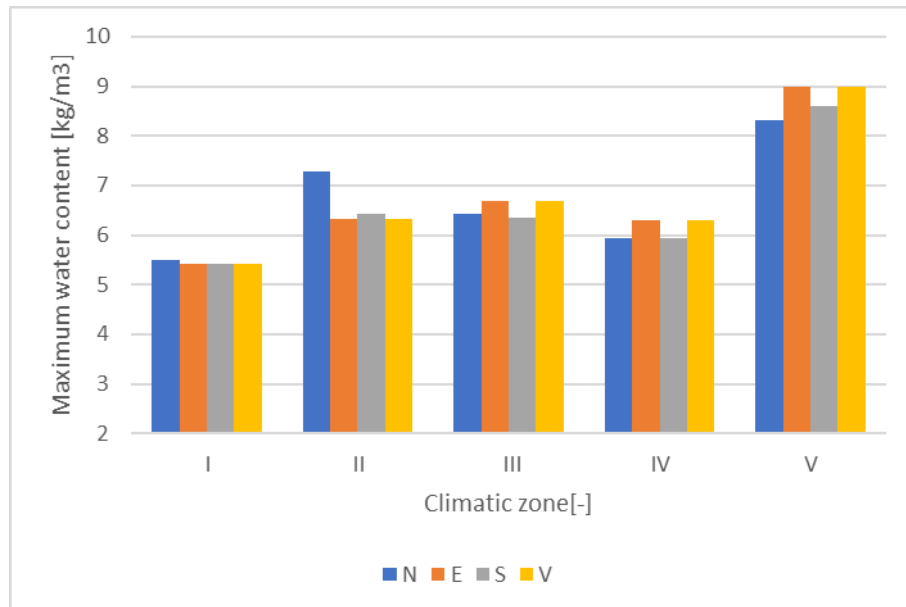


Fig. 7 – Graphic representation of maximum water content – same orientation.

Can be observed that when an element is subjected to identical cardinal orientation but varying environmental conditions specific to Romania's climatic zones, the maximum water content within the thermal insulation layer is observed to be at its minimum for climatic zone I and at its maximum for climatic zone V. Moreover, it is worth highlighting that the fluctuation in the upper limit of water content is significant, with a maximum percentage discrepancy of 49.65% between the minimum and maximum values, particularly about the West orientation.

5. Conclusions

Given that water content has a categorical impact on the thermal effectiveness of a heat-insulating material, comprehension of the fluctuations in the water content of a material is indispensable, whether it is traditional materials or those currently undergoing development. Also, the assessment of the risk of the growth of mould in building elements using thermal insulating materials whose behaviour has been studied less is a key point in the design of correct building elements.

This article highlights the evaluation of the water content of the thermal insulation layer, made of 90% hemp fibre and 10% two-component fibres, of a wall element exposed to different climatic conditions in Romania. The findings suggest a noteworthy variation in maximum water content within the thermal insulation layer across various climatic zones, with the greatest percentage difference being 49.65% between climatic zones I and V. Meanwhile, the analysis of results reveals a relatively lower variation in water content when the element is exposed to different cardinal points.

The simulation experiments conducted to evaluate mould growth in wall-type construction elements under diverse climatic conditions did not result in spore water content levels surpassing the critical threshold in any of the twenty scenarios tested. Hence, the findings suggest a low risk of mould growth.

To preserve the long-term performance and structural integrity of hemp insulation, the implementation of preventive measures in high-humidity environments is essential. These measures encompass adequate ventilation, the installation of water barriers and regular maintenance protocols. Failure to effectively manage moisture can result in diminished thermal efficiency, mold growth, and structural deterioration. Furthermore, elevated water content in hemp insulation may compromise the integrity of adjacent layers, highlighting the critical importance of integrating preventive strategies in building design and maintenance practices.

To advance our understanding of the thermal behaviour of hemp insulation materials, future research must be directed towards investigating the fluctuations in moisture content and the subsequent impact on thermal performance.

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VARIAȚIA UMIDITĂȚII ÎN STRATUL DE IZOLAȚIE TERMICĂ REALIZAT DIN FIBRĂ DE CÂNEPĂ ÎN CONDIȚII DE MEDIU SPECIFICE ROMÂNIEI: O EVALUARE

Efectuarea de investigații asupra comportamentului materialelor izolatoare termice, în timpul fazei de dezvoltare, este crucială pentru producerea de materiale cu performanțe termice optime. Un aspect indispensabil al acestor investigații este evaluarea variației conținutului de apă din stratul de izolație termică pentru diferite configurații de elemente din care acesta face parte. Umiditatea are un impact considerabil asupra conductivității termice a materialelor, ceea ce subliniază și mai mult importanța acestei evaluări. Articolul evaluează variația conținutului de apă în stratul de izolație termică din fibră de cânepă în condițiile distincte de mediu ale României prin simulări higrotermice care cuprind o perioadă de zece ani, utilizând un software specializat. Rezultatele indică o diferență semnificativă în conținutul maxim de apă din stratul de termoizolație, între diferitele zone climatice, cu o diferență procentuală maximă de 49,65% între zona climatic I. Pe de altă parte, analiza sugerează o variație relativ mică a conținutului de apă atunci când elementul este expus diferitelor puncte cardinale. Acest studiu consolidează importanța înțelegerii modului în care se comportă materialele de izolare termică și examinarea variației conținutului de apă în interiorul elementelor de construcție, în special în stratul de izolație termică. În plus, evaluarea probabilității dezvoltării mușcăiului este o verificare esențială care nu poate fi trecută cu vederea.

