THERMAL PROPERTIES OF AN ADOBE BRICK WALL: ADAPTING TRADITIONAL TECHNIQUES TO CONTEMPORARY LIVING STANDARDS

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Abstract

Nowadays, the topic of energy consumption in the field of construction has become a pressing issue in procuring efficient materials and technologies. After introducing the nZEB standards, respectively the passive house concept, it is more and more important to highlight the built-in primary energy factors, namely the amount of energy saved by the use of adequate materials, stratifications and energy-efficient systems. Further discussions then develop into determining the life cycle of materials in order to justify their choice in the detriment of others.

Starting from these debates, earth used as a building material comes in as a viable response due to its thermal qualities reservoir due to the massive walls of this type of construction. These properties recommend it in creating an adequate thermal comfort using eco-friendly resources.

Adobe was used mainly in the second period of colonization in the Banat area of Romania. The case study presented in this paper starts from the still existing building stock and it is followed by the comparative analysis of possible stratifications to induce the thermal comfort inside a new building constructed using the adobe technique as opposed to modern conventional burnt bricks.

In the last 30 years in Romania, although European construction regulations have been gradually adopted, the issues of energy efficiency and interior comfort have not been at the attention forefront of either designers or beneficiaries, nor the study of traditional building techniques. That is why the aim was to highlight that by using local traditions with eco-friendly materials even the toughest standards can be achieved concerning passive buildings requirements developed in Germany. The methodological approach was to compare different specific stratifications to collect the primary data in a quantitative computer based simulation procedure.

Keywords: Sustainability, earth constructions, thermal properties, adobe technique, passive house.

1. INTRODUCTION

The adobe technique had its downfall at the end of the 19th century when the abundant supply of cheap manufactured construction materials began. During the oil crisis of the 1970s, a renewed interest in earth construction started due to their low demand for energy during fabrication and because it provided a basic standard of thermal comfort in climatic regions where they had been traditionally used. (E.Rico-Guardia, 2010, pp.2211). The majority of adobe constructions are located in less developed countries. Unfortunatelly, the fact that earth construction is associated with low income status is probably one of the most important reasons that explain why these less developed countries try to emulate the use of unsustainable construction materials in an act of achieving a so-called higher status while neglecting environmental issues. Earth constructions can also be found in developed countries (Germany, United Kingdom, France and Switzerland), where a growing awareness towards energy consumption can be witnessed.

In this particular context, earth construction assumes an advantage that makes it extremelly competitive when compared to conventional modern materials and construction techniques, because it has low embodied energy, thus making it suitable for the requirements of nZEB standards (nearly Zero-Energy Buildings) and the passive house concept. It is proven that the appropriate choice of materials with low environmental impact can contribute decisively to reduce the energy consumption, the greenhouse gas emissions and the waste production of the building choice. The building's life cycle analysis introduces greater significance for formulating strategies to achieve reduction in primary energy. That is why there is a potential of reducing embodied energy consumption through use of materials that require less energy during manufacturing (T.Ramesh, R.Prakash, K.Shukla, 2010, pp.1592-1600).

Unlike the modern building industry, traditional materials are proven to be more eco-friendly and have nearly zero carbon footprint. The contemporary building sector with its high rate of growth has referred to traditional building techniques as being primitive. The lack of industrialization has become an act of poverty, whereas earth construction techniques emphasize the activity that used to form collaborative communities, as proved in the presented study case, and unique designs.

II. THE ADOBE TECHNIQUE- TRADITION IN THE BANAT AREA

The Habsburg Empire colonized the Banat area starting with the 18^{th} century and the local soil was the binding material on which constructive methods were adapted to existing resources. The transition took place gradually, starting from the available materials and ending with a transfer of knowledge and adaptation process between the local population and the new settlers (Germans, French, Italians).

The adobe technique consists of local earth mixed with natural fibers, molded into rectangular prisms that are in the sun. The composite material is made out of earth (55-75% sand, 10-30% silt and 15%clay) mixed with water and an organic material such as straw or dung. The physical properties of the local earth, as emphasized by the authors in former studies (E.R.Florescu, S,M, Bica, 2018,pp.10-18) confirm that the material is ideally suited for the adobe technique by comparing the results in terms of composition with benchmark values proposed by the Craterre Institute (R. Anger, L.Fontaine, 2009,pp504-505) and the german regulations of Dachwerband Lehm. (M. Duculescu Dachwerband Lehm, 2010, pp. 47-51).

Adobes can serve as a significant heat reservoir due to the thermal properties inherent in the massive walls typical in traditional adobe constructions. Energy storage occurs through the heat of crystallization rising from the salts within the clay structure of the material. The effects of rain wetting and the absorption and evaporation of water vapours due to the salts that act as phase changing components within the wall, increase the accuracy of predicting the performance of adobe structures (A.Michael, M. Philokyprou , S. Thravalou, I. Ioannou. ,2016, pp.1-7).

The density of the material varies from 600 to 1040kg /m3 with a thermal conductivity - λ (lambda) of 0.17 to 0.47 W / mK. The massive walls require a large and relatively long input of heat from the sun (radiation) and from the surrounding air (convection) before they get warm through to the interior. After the sun sets and the temperature drops, the warm wall will continue to transfer heat to the interior for several hours due to the time-lag effect. Thus, a well planned adobe wall of the appropiate thickness is very effective at controlling inside temperature through the wide daily fluctuations.

Fig.1.(left). Charlottenburg, the round village established during the colonization - 18^{th} century, https://editiadedimineata.ro/charlottenburg-povestea-singurului-sat-circular-din-romania/15.06.2019;

Fig.2.(right). Typical household in the Banat area, Doclin - 19^{th} century, Storefront of Josefina Friedmann, http://www.comuna-doclin.ro/istoric/10.05.2019;

Fig.3. Juxtaposition between a demolished adobe house and a new burnt brick construction – Birda, Timiș county/Author: E.R. Florescu 10.05.2019;

III. ENERGY REQUIREMENTS OF MODERN MATERIALS

Not all modern building materials have great insulating properties or if they do, they have a great amount of embodied energy due to their fabrication methods or recycling actions afterwards. That is why the modern building industry consumes up to 40% of all world energy, unlike traditional buildings which adopt passive design constructs. The life cycle of a building depends on the operating (80-90%) and embodied (10-20%) energy of the entire construction (M. Khasreen, P. Banfill, G.F. Menzies. 2009, pp.674-701).

For a conventional residential building, the normalised life cycle energy is in the range of 150-400 kWh/m2 per year. This amount refers to the primary energy content, as in the energy required to produce a component. In most cases only the non-renewable portion of this energy is of interest, that is the contribution derived from fossil fuels or nuclear energy (T.Ramesh, Ravi Prakash, K.K. Shukla 2010, 1592-1600).

The passive house standard, the world's leading standard in energy efficient construction, stands for quality and comfort. Passive houses require very little energy to achieve a comfortable temperature all year around, making conventional heating an air conditioning systems obsolete. In the energetic evaluation of a component, the primary energy content should also be taken into account, by considering the total energy demand of the component: primary energy content plus heat loss during the estimated service life (https://www.passivehouse-international.org/index.php?page_id=150, 10.06.2019).

Following the passive house conditions, the primary energy doesn't have to exceed 120kWh annually for all domestic applications (heating, cooling, hot water and domestic electricity) per square meter of usable living space, while components have to reach low thermal transmittance (U-values), with minimised thermal bridges between them.

As a comparison in terms of energy, compressed stabilized earth blocks are more eco-friendly than burnt bricks and their manufacture consumes less energy (15 times less) and pollute less than fired brick (eight times less).*Adobe constructions are not associated with the adverse effects of indoor air volatile organic compounds (VOCs) so the occupants of these buildings have a superior air quality (*F.Pacheco-Torgal, S.Jalali, 2012, 512-519).

IV. COMPARITIVE ANALYSIS BETWEEN WALL STRATIFICATIONS

The case study presented in this paper proposes a comparative analysis of possible material layers to solve the thermal comfort inside a new home built using the adobe technique as opposed to modern conventional burnt bricks. The aim is to highlight that by using local traditions with eco-friendly materials, even the toughest standards can be achieved. The methodological approach was to compare different specific wall stratifications to collect the primary data in a quantitative computer based simulation procedure using Ubacus and HTflux software.

The wall layerings have to meet the requirement for a U-value of less than 0.15 kWh / m2 according to the passive house standard developed in Germany. At each stage of the study, elements were considered that have similar properties or have an optimal compatibility to the basic materials: burnt bricks with vertical hollows used nowadays and the ecological alternative, adobe bricks. To start with, 2 items with similar properties were compared – the burnt brick POROTON PH Plan-T 36,5cm with a thermal conductivity of 0.18 W / m K and a modern adobe with λ = 0.21 W / m K for an element of 11,5cm (AGATON LEHM Leichtlehmsteine 2DF). In the first scenario, a single row of Poroton bricks is used, while for the second scenario, the adobes were layered in two rows, similar to an English bond, with a total thickness of 36cm, thus resulting similar measurements and similar conductivity values.

If in the first case scenario, for the conventional burnt bricks with vertical hollows , a mineral wool was used with a thermal conductivity equal to 0.032 W / m K, while in the second scenario – adobe bricks, a thermal insulation made out of wood fibers was suited with a λ = 0.039 W/m K. In the last case it is necessary to supplement the thermal insulation on the inside with a composite straw and clay construction board to avoid condensation on the outside of the thermal insulation. This complementary board also has the role to compensate for the masonry's imperfections, respectively, to support the vapour barrier layer with a diffusion thickness of 5m.

From the temperature and humidity diagrams, it is observed that the water vapours do not condense on the internal surface of the masonry having the values of:

- for burnt bricks with vertical hollows - inside surface: 19,1º C 32,4% r.h. (relative humidity), outside surface: 12,2ºC, 27,2% r.h.;
- for adobes: inside surface 18.5 ° C, 28.5% r.h, outer surface: 12.7 ° C, 28.6% r.h.

Comparing the two stratifications by thermal simulations using german standards, the following were concluded: the thermal resistance values are similar with a thickness difference of only 4 cm, also the weight per square meter, the internal temperature, the humidity and the heat storage capacity are similar. The phase change characteristic is much higher than the recommended 12h in the case of modern masonry which demonstrates that the components used give a particularly good thermal protection. For the adobe bricks, the time lapse is much higher but this is not a drawback because the temperature amplitude attenuation is usually so strong that outdoor temperature fluctuations are not immediately felt in the interior environment.

The drying reserve factor proves that in case of adobes the drying time is much faster compared to conventional bricks, which shows the permeability of the adobe material and its hygroscopic properties. Also heat loss is prevented in the adobe masonry proven by the lower heat flux value compared to that that of burnt bricks. This proves once again that the porosity of natural materials is much better suited to fluctuating environmental conditions, allowing for a balance of the thermal comfort without lowering the required standards.

The moisture protection survey is based on the iterative method of the 2D finite element. Unlike conventional standards, moisture-varying vapour barriers are considered while the capillary conductivity of materials is neglected - a disadvantage in determining the characteristics of adobe masonry. Also, the moisture entry through diffusion and residual leakage at the level of sealing is not taken into account.

Considering the values mentioned above, it is easy to conclude that the proposed stratifications have similar values, thus demonstrating that the ecological alternative of modern adobes can comply with the passive house requirements, if used correctly.

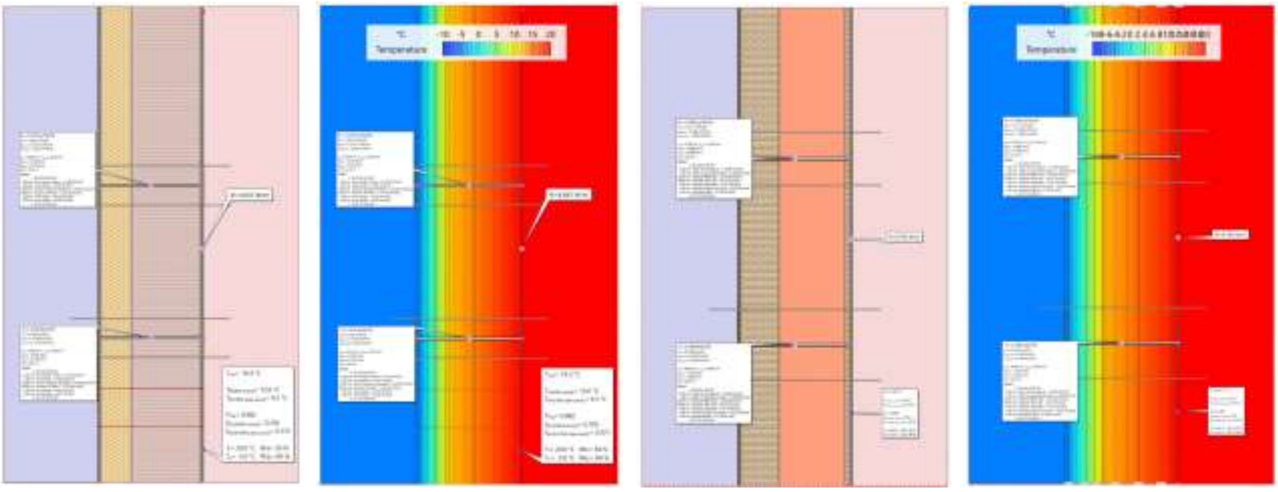


Fig. 4. (a,b,c,d,). Comparative analysis in HTflux of an conventional brick wall (left -a,b) and a modern adobe masonry (left -c,d) showing heat transfer through the exposed surface;

Table 1. Characteristics of a conventional burnt brick POROTON PH Plan-T 36,5cm

#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	Temp. [°C] max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0.130 (0.250)	19.2	20.0				
1	0,3 cm	Lime render	0,870	0,003	19,1	19,2	0,03	-	4,2	1000
2	2 cm	Lime render	0,870	0,023	19,1	19,1	0,20	-	26,0	1000
3	0,05 cm	Vapor retarder sd=2,3m	0,220	0,002	19,1	19,1	2,30	-	0,1	1700
4	36,5 cm	Poroton PH Plan-T 365 0.18 (ab 1990)	0,180	2,028	12,2	19,1	1,83	-	292,0	1000
5	16 cm	Knauf Insulation Fassaden-Dämmplatte TP 432 B	0,032	5,000	-4,8	12,2	0,16	-	4,8	830
6	1 cm	Lime render	0,870	0,011	-4,9	-4,8	0,10	-	14,0	1000
7	0,3 cm	Lime Cement Render	1,000	0,003	-4,9	-4,9	0,11	-	5,4	1000
		Thermal contact resistance		0,040	-5,0	-4,9				
	56,15 cm	Whole component		7,241			4,72	-	348,5	

U-value: 0,138 W/m²K

Temperature of inside surface: 19,2 °C
Temperature of outside surface: -4,9 °C

Table 2. Characteristics of a modern adobe wall - AGATON LEHM Leichtlehmsteine 2DF

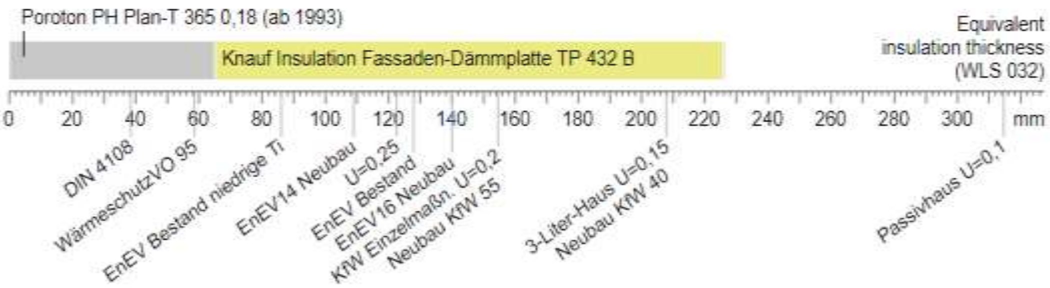


Table 2. Characteristics of a modern adobe wall - AGATON LEHM Leichtlehmsteine 2DF

#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	19,1 20,0				
1	0,3 cm	Claytec Lehmoberputz fein 06	0,910	0,003	19,1 19,1	0,02	-	5,4	1000
2	1 cm	Claytec Lehmoberputz grob mit Stroh	0,910	0,011	19,1 19,1	0,05	-	18,0	1000
3	0,05 cm	Vapor retarder sd=5m	0,220	0,002	19,1 19,1	5,00	-	0,1	1700
4	2,2 cm	Claytec Greentech 700	0,130	0,169	18,5 19,1	0,26	-	15,4	1400
5	24,5 cm	AGATON LEHM Leichtlehmsteine 2DF 700	0,210	1,167	14,5 18,5	1,23	-	171,5	1000
6	11,5 cm	AGATON LEHM Leichtlehmsteine 2DF 700	0,210	0,548	12,7 14,5	0,58	-	80,5	1000
7	20 cm	STEICOtherm dry	0,039	5,128	-4,8 12,7	0,60	-	22,0	2100
8	0,5 cm	gräfix 61 Haar grob · Haar-Kalk-Grundputz	0,890	0,006	-4,8 -4,8	0,10	-	6,3	1000
9	1 cm	gräfix 61 fein · Kalk-Dünnschichtputz	0,890	0,011	-4,9 -4,8	0,10	-	12,5	1000
		Thermal contact resistance		0,040	-5,0 -4,9				
	61,05 cm	Whole component		7,215		7,93	-	331,7	

U-value: 0,139 W/m²K

Temperature of inside surface: 19,1 °C
Temperature of outside surface: -4,9 °C

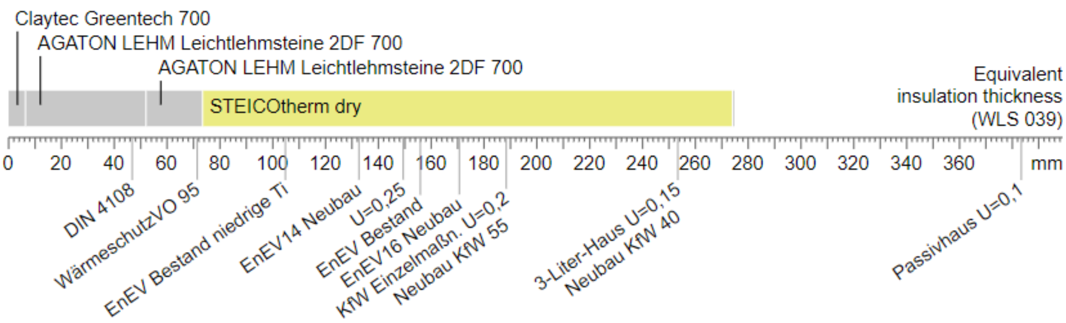


Table 3. Comparative analysis of the case scenarios using HTflux and Ubacus software

Values/ stratification	Wall 1 – Conventional fired bricks+mineral basaltic insulation boards	Wall 2 – Modern adobes + wood fibre insulation boards
HTflux		
R [m^2K/W]	7,2273	7,224
U [W/m^2K]	0,138	0,139
Φ [W/m]	8,665	8,76
T_{min} [° C]	19,6	19,2
Ubacus		
EnEV	0,138<0,24	0,140<0,24
PEI [Kwh/m^2]	154	> 101

Condensate [kg/m^2]	0	0
s-d value [m]	4,7	3.1
Thickness [cm]	56,15	60,5
Weight [kg/m^2]	349	349.6
Interior Surface [° C]	19,1	19,1
Relative humidity [%]	53	53
Temp. amplitude damping [1/TAV]	>100	>100
Phase shift [h]	24	-
Heat storage capacity [Kj/m^{2}K]	277	288
Drying reserve [g/m^{2}a]	4361	2897

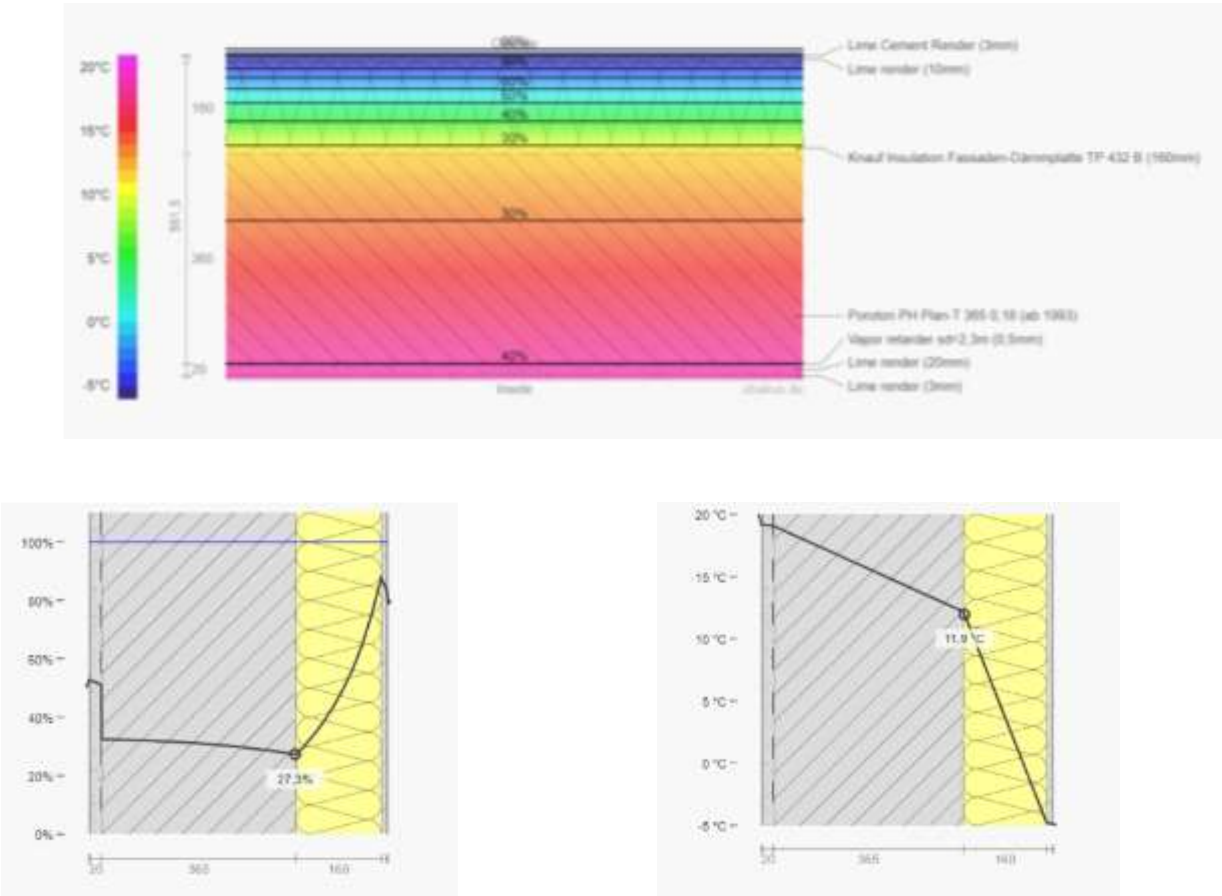
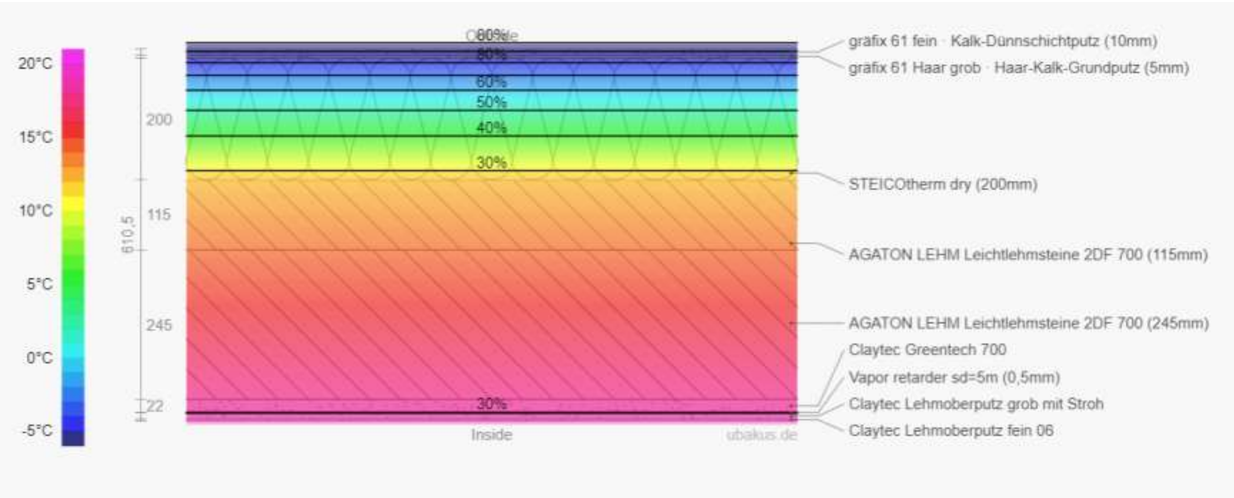
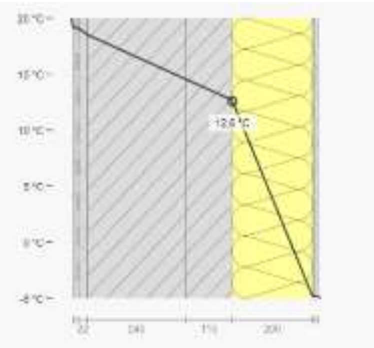
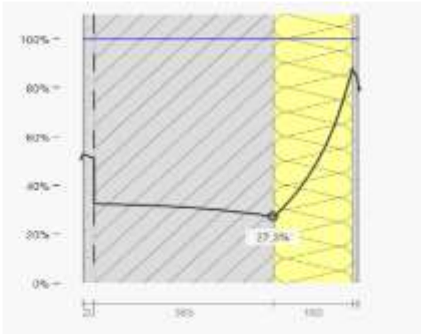


Fig. 5. Diagrams showing the temperature flow and relative humidity for the 2 case scenarios: up - conventional burnt brick, below – adobe masonry;

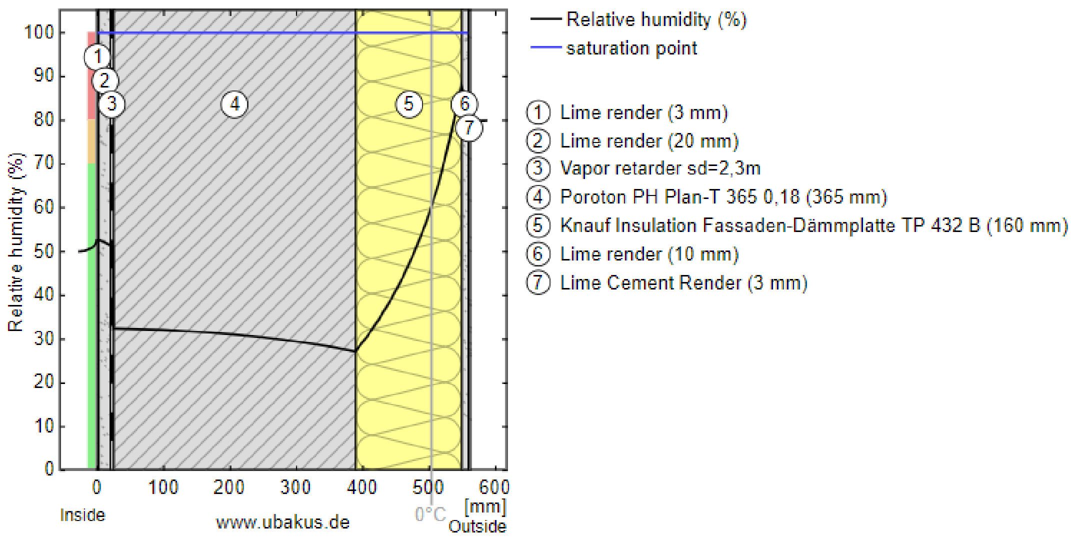






Moisture protection (via u-wert.net 2D finite elements)

The following figure shows the relative humidity inside the component, 100% = condensate.



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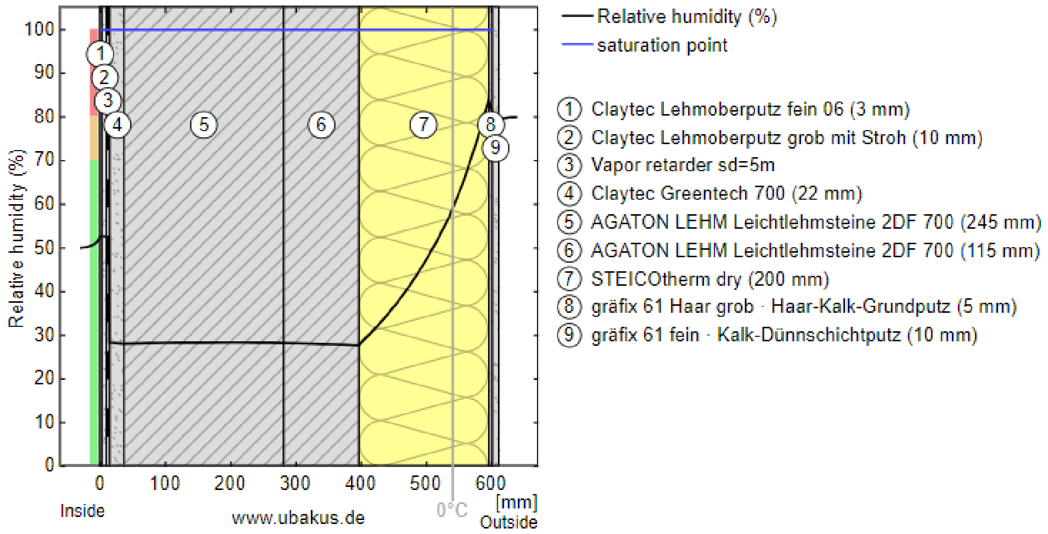

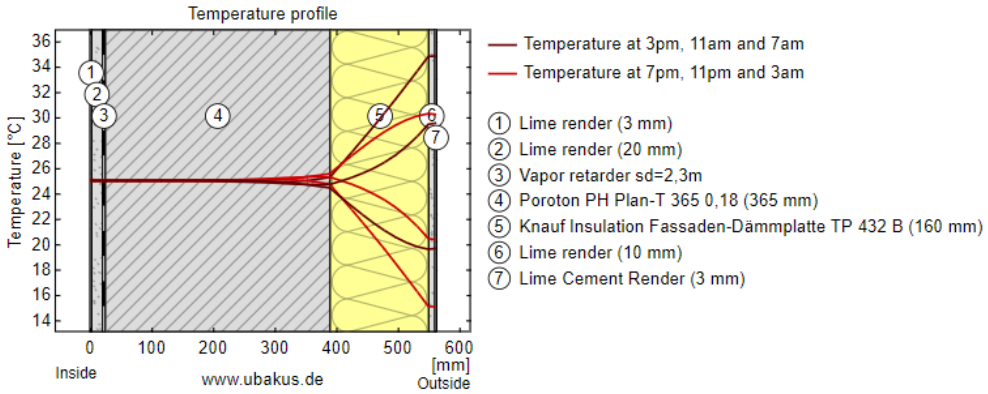

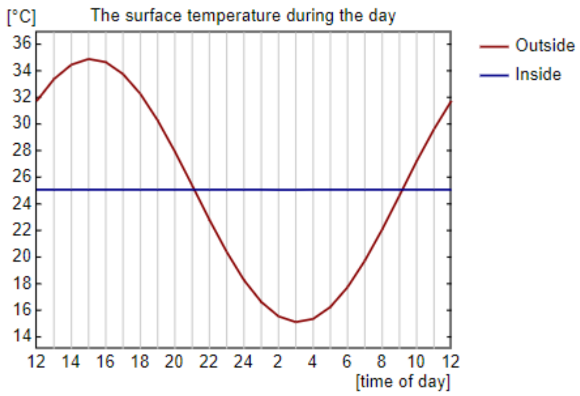

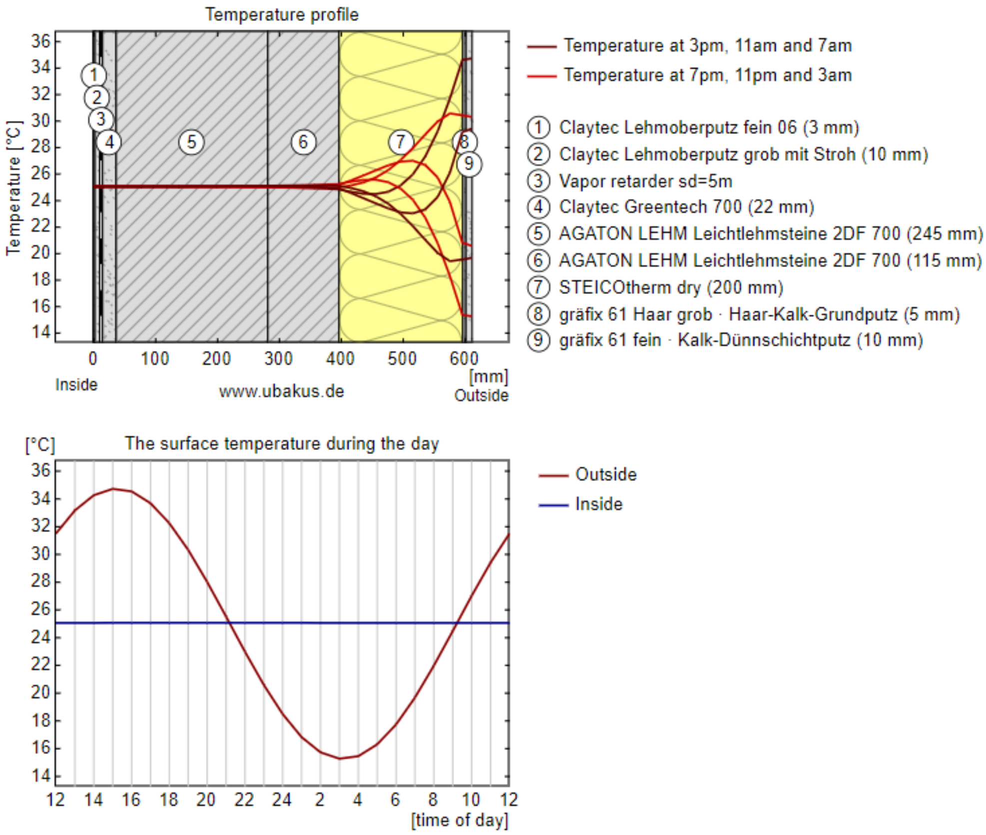

Fig. 6. Diagrams showing the moisture protection and the surface temperature variation for the 2 case scenarios proposed: left - conventional burnt brick, right – adobe masonry, Ubacus software.

V. CONCLUSIONS

In the Banat area, the properties of the local earth confirm that the material is ideally suited for the adobe technique delivering a sustainable response through the adequate use of existing resources. The need to build while preserving natural elements/resources has contributed to the revival of earth constructions at a global scale as well as a local one. There are many places where, as in the case of the studied area of Banat, these techniques have been used for a long time but nowadays little is acknowledged about their importance in defining a specific identity. Earth materials were replaced by industrial materials following the EU regulations that meet two important requirements: mechanical improvement and efficient production but do not take into consideration the embodied energy efficiency and interior comfort.

The conventional construction materials follow the path of industrialization and maximization of profit, while the traditional techniques of construction require work based on a strong collaborative spirit and focus on delivering exclusive designs based on adapting traditions to the comfort of the user. Due to the raising awareness of embodied energy used in construction materials, initiatives propose reinvented materials with similar performances to the dominant existing alternatives, as shown in the presented comparison between conventional burnt bricks and contemporary adobe. This study highlights another narrative based on the potential to renew adobe's qualities and properties and thus respond positively to contemporary environmental concerns and challenges. This initiative goes beyond the purpose of an actual project, it is part of a cultural vision of environmental action that also helps to emphasize the specific local building technique.

Earth constructions can represent a viable idea of development in the period of climatic changes. Because of its great flexibility of implementations, its qualities of durability resistance to weather and fire, adobes are a technique of the future and further analysis should be made in order to determine the characteristic values as-build in contemporary projects.

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