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A Comparison of Straw-Bale and Conventional Brick Buildings in View of Energy Efficiency and Environmental Performance

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ABSTRACT

In the past few years, traditional building materials experienced a kind of renaissance. This is in part due to the ecology considerations. Moreover, some traditional materials offer feasible and affordable alternatives to conventional materials. In this contribution, two real, recently erected buildings in Hungary (a conventional brick construction and a building with straw-bale walls) were used as the basis for an extensive comparison of energy and environmental performance. As these buildings are different in terms of geometry, size, and location, two corresponding virtual buildings were generated: The actual brick building was virtually recreated using straw-bales, whereas the straw-bale building was virtually recreated using brick. Thus, real and virtual buildings can be compared directly. Furthermore, two additional buildings were included in the analysis whose constructions include both brick and straw bale. Using both simplified and numeric methods, the heating demand of both real and virtual buildings were derived. Moreover, environmental performance indicators Global Warming Potential, Acidification Potential, and Primary Embodied Energy were calculated. The comparison results point to certain advantages of the straw-bale application in view of the buildings' ecological performance.

KEYWORDS: straw-bale, brick, heating demand, ecological performance

1 INTRODUCTION

As with other European countries, energy use has increased in Hungary in the past few years Hungary. According to enerCEE (AEA 2012), in 2008, 46.4 percent of the final energy demand in Hungary was related to services, agriculture and households. Furthermore, the European Environmental Agency states that in 1990, 75 percent of the end users' energy consumption was due to space heating. Since then many energy-saving measures (e.g. building retrofit) were realized. Nonetheless, space heating still represents two thirds of the overall energy use. Furthermore, Hart and Hart (2013) state that given an expected worldwide range of oil reserves of about 80 years, current construction practices may soon not be feasible any longer. Thus, a renewed interest is emerging with regard to traditional low-tech and low-energy building materials and technologies.
In this context, the present contribution deals with the ecological and energy performance of straw-bales as a building and insulation material via an extended case study: The geometry, location, and morphology of two recently erected, comparable detached houses (one constructed with typical brick construction, the other one constructed from straw bale) were used as a base for six different cases. Key energy and environmental indicators were calculated for both the two real buildings and four virtually recreated variations of these buildings (corresponding in geometry and location, but under virtual application of different constructions).

The research question examined in this contribution can thus be formulated as “How do straw bale buildings perform in comparison to conventional brick buildings in terms of energy efficiency and environmental performance?”
Straw-bale constructions, per se, are not a new invention. In vernacular building construction in different regions of the world straw was and is used for roofs and shades. Modern constructions that utilize straw-bales (pressed compounds of dried straw) as a load-bearing material for exterior walls are known since around 1900, evolving in the United States first. Known advantages of straw bale construction are utilization of an agricultural waste product, biological characteristics of straw, the low embodied energy, as well as the fire-resistance (with adobe plaster). A potential disadvantage (in case of improper realization) is the vulnerability against water and rodents.
In Hungary straw bale constructions appeared in larger numbers in the past few years. This may be due to a surplus production of straw-bales, making them a rather affordable and locally available building material (Medgyasszay and Novak 2006).

2 METHODOLOGY

2.1 Examined buildings

A conventional brick building (referred to as 1_B, see Figure 1) designed by Hungarian Architect András Fosztó and a straw-bale building (2_S, see Figure 2) designed by Hungarian Architect Tibor Jandrasits were chosen for this study. Both buildings are of residential use, located in Hungary (1_B: Piliscsaba; 2_S: Bozsok), and were constructed in the past few years (1_B: 2011, 2_S: 2006). As the architects kindly agreed, the original plans could be acquired, including site plans, floor plans, sections and 3D models. Additionally, in-Situ visits ensured the correspondence of the plans with the final buildings.
1_B features external walls of modern perforated bricks (POROTHERM 38N+F, Wienerberger n.d.) with externally mounted 10cm of EPS insulation, and plaster on both sides. Fenestrations were originally intended to be passive house windows, but were later replaced with standard plastic-framed windows with a U-Value of 1.40 $W.m^{-2}.K^{-1}$, due to cost cuts. In contrast, the external walls of 2_S consist of 50 cm wire-reinforced straw-bales covered with 5 cm of clay and lime-wash on both sides. Fenestration consists of highly-insulated windows (U-Value of 1.00 $W.m^{-2}.K^{-1}$).

Next, the variants 1_S, 2_B, 1_BS and 2_BS were generated. These buildings correspond to their real counterparts 1_B and 2_S in geometry and location, but with different building constructions applied. For instance: 1_S and 1_BS were based on 1_B, but use the straw-bale construction or brick construction insulated with straw (instead of EPS). Table 1 offers a detailed overview about the key features of all six examined buildings, while Figure 3 illustrates the three different types of external walls used for this study. The U-values of all surveyed buildings’ thermal envelopes are shown in table 2.

Figure 1: Building 1_B, Piliscaba, Hungary; Architect: Andras Foszto

Figure 2: Building 2_S, Bozsok, Hungary; Architect: Tibor Jandrasits

Table 1 Overview of the studied buildings

	1_B	**1_S**	**2_B**	**2_S**	**1_BS**	**2_BS**
Location	Piliscsaba	*Virtual*	*Virtual*	Bozsok	*Virtual*	*Virtual*
Floors	Ground floor + unheated roof					
Date of construction	2011	*Virtual*	*Virtual*	2006	*Virtual*	*Virtual*
Wall construction	Brick	Straw-bales	Brick	Straw-bales	Brick+Straw	Brick+Straw
Brutto heated floor area	112.3 m^2		199.3 m^2		112.3 m^2	199.3 m^2
Brutto heated volume	345.8 m^3		673.7 m^3		345.8 m^3	673.7 m^3
Building Envelope area	386.4 m^2		647.0 m^2		386.4 m^2	647.0 m^2
Opaque envelope area (% of building envelope)	367.2 m^2 (95.03%)		619.2 m^2 (95.71%)		367.2 m^2 (95.03%)	619.2 m^2 (95.71%)
Transparent envelope area (% of building envelope)	19.2 m^2 (4.97%)		27. 8 m^2 (4.29%)		19.2 m^2 (4.97%)	27.8 m^2 (4.29%)
Characteristic length	0.90 m		1.04 m		0.90 m	1.04 m

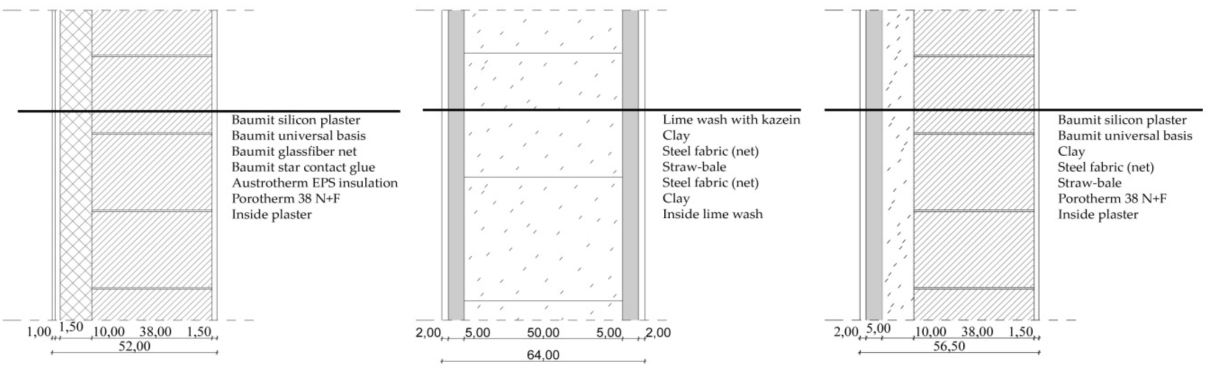

Figure 3: Layers of the outside walls in the different constructions (left: “Brick” used in 1_B and 2_B; middle: “Straw-Bale” used in 1_S and 2_S; right: “Brick+Straw” used in 1_BS and 2_BS)

Table 2 U-values [W.m^{-2}.K^{-1}] of constituting building elements of all six buildings.

U-values W.m^{-2}.K^{-1}	**1_B**	**1_S**	**2_B**	**2_S**	**1_BS**	**2_BS**
External wall	0.200	0.094	0.200	0.094	0.205	0.205
Ceiling to attic	0.168	0.101	0.168	0.101	0.212	0.212
Floor to the ground	0.370	0.544	0.370	0.544	0.370	0.544
Windows	1.400	1.400	1.000	1.000	1.400	1.000
Windows g-value	0.550	0.550	0.550	0.550	0.550	0.550

Figure 4: Locations of the real and virtual buildings in Hungary
(Bozsok: 2_B, 2_S, 2_BS; Piliscsaba: 1_B, 1_S, 1_BS)

2.2 Applied evaluation methods

For the evaluation of the energy and ecological performance of all six buildings, the following instruments and indicators were used:

- Dynamic hourly thermal simulation was applied for evaluation of the buildings' energy performance. As the pertinent indicator, the annual heating demand was chosen, which was derived with the simulation tool TAS (EDSL 2010). Figures 5 and 6 show the building representations constructed in this software of building 1_B and 2_S.
- Simple calculation methods were used to estimate environmental impact. The derived indicator was the OI3-Indicator (IBO 2011). This indicator incorporates Global Warming Potential (GWP, CO_2-equivalent emissions), Acidification Potential (AP, SO_2-equivalent emissions) and Primary Energy Content (from non-renewable energy sources, PEC, MJ of invested energy). All three parameters are calculated based on the sums of each component's mass or area: For instance, the GWP-value is derived directly from the amount of CO_2 and CO_2-equivalent gas emissions from the production of building components. The tool used for evaluation was A-Null Archiphysik 10 (A-Null 2011, Battisti 2011).

It has to be noted that the input information for both indicators requires a comprehensive set of data. While the data concerning properties of the building elements for the thermal simulation was partly covered by the architects' fact sheets (thermal conductivity of building elements), missing information was taken from standard databases incorporated in Archiphysik (specific heat and density). For internal gains (lighting, occupancy, equipment) and ventilation rates typical values for residential buildings (as stated in OENORM 2011) were used. Additionally, schedules for these values were applied, assuming that the buildings are not occupied the whole day on workdays, but are fully occupied on weekends. Input assumptions concerning internal gains and ventilation rates (identical for all six cases) are included in Table 3. The climate data used for the simulation was derived from the software METEONORM (Meteonorm 2012): For 1_B, 1_S and 1_BS climate data from Budapest was used, while for 2_B, 2_S and 2_BS climate data from Györ (closest weather station to Bozsok) was applied (compare Figure 4 for locations).

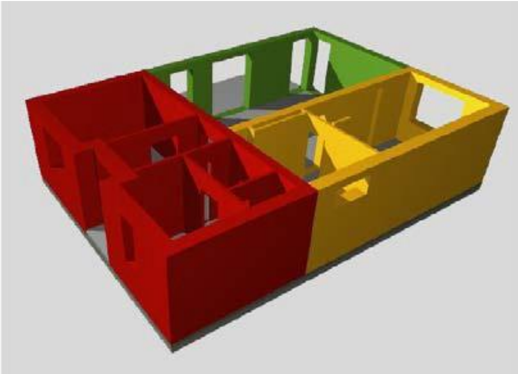

Figure 5: simulation model of building 1_B

Figure 6: simulation model of building 2_S

Table 3: Internal gain and ventilation rate assumptions (used in dynamic thermal simulation)

Time	Weekend	Weekday		
	Whole day	00:00 – 09:00	09:00 – 16:00	16:00 – 24:00
Internal Gains	3.75 $W.m^{-2}$	3.75 $W.m^{-2}$	0.00 $W.m^{-2}$	3.75 $W.m^{-2}$
Ventilation rate	0.4 h^{-1}	0.4 h^{-1}	0.0 h^{-1}	0.4 h^{-1}

Concerning the OI3-Indicator it has to be stated that used data was completely taken out of Archiphysik database (A-Null 2011, based on IBO 2011), as the producers and vendors of building materials provide only rudimentary data about the ecological performance of their products.

3 RESULTS AND DISCUSSIONS

3.1 Energy performance indicators

Table 4 shows simulated heating demand together with the transmission losses through the envelope.

Table 4 Simulated values of the buildings' energy performance indicators

	1_B	**1_S**	**2_B**	**2_S**	**1_BS**	**2_BS**
Heating demand [$kWh.m^{-2}a^{-1}$]	44.41	36.84	40.61	34.17	46.31	42.02
Transmission loss [$kWh.a^{-1}$]	7930	7110	11895	10141	7143	10085

As straw bale constructions provide a higher insulated envelope than their brick counterparts (Table 2), it could be expected that they would display a lower heating demand. Nonetheless, all simulated buildings would be classified as class B buildings following OIB classification (OIB 2011a and OIB2011b). Figure 7 illustrates the monthly transmission losses of buildings 1_B and 1_S.

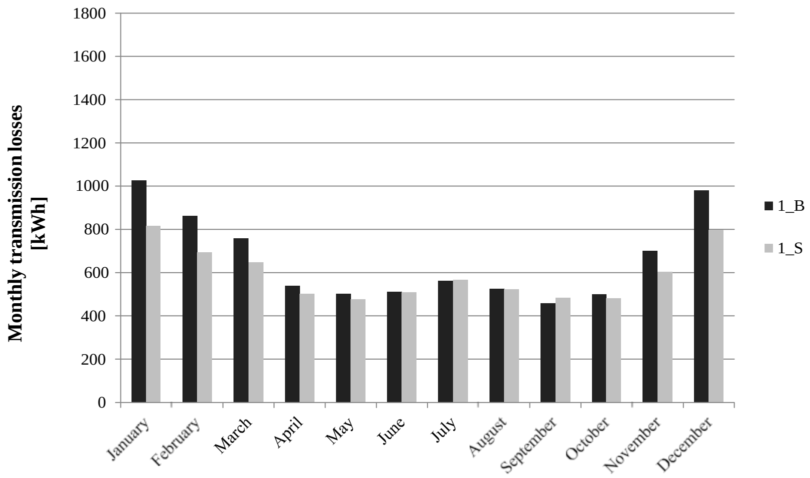

Figure 7: Simulated monthly transmission losses in 1_B and 1_S

3.2 Environmental indicators

Table 3 represents the environmental indicators of the examined buildings based on the OI3-evaluation methods (OI3-points). In general, the brick constructions show higher values in all three categories (Global Warming Potential GWP, Acidification Potential AP, and Primary Energy Content PEC). Note that – due to the calculation scheme – values depicted as “0” might have had a negative calculation result. These were set to zero, following the idea, that the building with the lowest impact on environment is the non-built one.

Table 3 Simplified calculation results of the buildings’ environmental indicators

	1_B	1_S	2_B	2_S	1_BS	2_BS
GWP [-]	58,93	0	61,92	0	42,04	36,56
AP [-]	51,17	13,32	64,25	22,88	2,05	0
PEC [-]	61,01	2,29	80,82	11,05	22,05	18,43

The brick constructions (1_B, 2_B) show higher values in all three categories than straw bale constructions (1_S, 2_S). Specifically, Global Warming Potential associated with straw bale constructions is negligible. Results shown in Table 3 pertain to whole buildings. To focus on the exterior wall construction (the salient difference between the buildings in the present study), Figure 8 illustrates PEC, GWP, and AP for brick (B), straw bale (S), and brick+straw (BS) wall constructions. The straw bale construction displays again the lowest values for all three indicators.

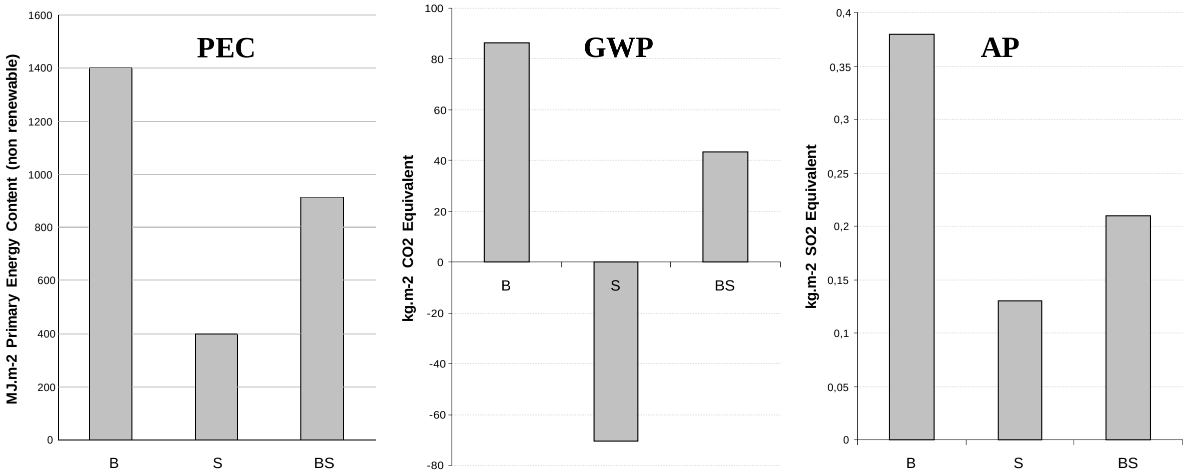
PEC
MJ.m-2 Primary Energy Content (non renewable)
1600
1400
1200
1000
800
600
400
200
0
B
S
BS
GWP
kg.m-2 CO2 Equivalent
100
80
60
40
20
0
-20
-40
-60
-80
B
S
BS
AP
kg.m-2 SO2 Equivalent
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
B
S
BS

Figure 8: Calculated PEC, GWP, and AP values for the three different external wall constructions (B, S, BS)

4 CONCLUSION & FUTURE RESEARCH

Using simulation and calculation, we compared straw bale and brick constructions. Both energy and environmental impact indicator values are rather low in case of straw bale constructions. Hence, straw bale appears to be a promising building material for the future in view of energy and environmental performance. Note that a number of other important issues pertaining to the straw bale constructions was not addressed in the present study, including, for example, condensation risk, moisture impact, and potentially necessary chemical treatment. Likewise, structural questions (load-bearing behaviour), which could be a challenge in large-scale realizations were not addressed. In future research, these and other issues need to be addressed, including the economic impact of large scale application of straw bales on the agricultural market and prices, and the need for improved marketing and promotion.

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