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House Embodied Energy and Zero Energy Building Concept

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Seeking to mitigate climate change it is impossible to avoid radical changes in construction sector, because it accounts for 40% of primary energy use for buildings operation in Europe and other countries. Production of building materials also affects climate change and environment quality. The concept of zero energy building (ZEB) emphasizes energy efficiency, energy saving and renewable energy use during the operation of buildings and it is a necessary step in changing the present situation. Nevertheless there are more possibilities for improving building sector sustainability. The article presents analysis of embodied energy reduction using straw bales and other local materials for wall construction. Estimations have shown that replacing a structural component as bricks with local wood, and thermal insulation material – stone wool with straw bales, it is possible to reduce embodied energy and embodied carbon of a wall more than 7 times. Pressed straw being a building material with good thermal properties, straw bale buildings could meet the passive houses standard or help fulfilling the concept of zero energy building without additional harm to the nature of extra thermal insulation use.

Key words: *embodied energy, embodied carbon, straw bale construction, zero energy buildings, climate change.*

1. Introduction

The main motivation of developing zero energy buildings (ZEBs) is saving of energy. Energy use directly impacts climate change, environment quality, fossil fuels depletion and thus – economy and human lives.

There are several definitions of ZEB emphasizing energy efficiency, energy saving and renewable energy use during the operation of a building: “a net zero-energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies” (Torcellini 2006, US DE 2007, NREL RC 2006, Pratsch 2006); “nearly zero-energy building means a building that has a very high energy performance: the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” (European Parliament 2010).

It is agreed that from 2019 newly constructed buildings should be nearly zero energy buildings in the EU; and the U.S.A. Department of Energy Buildings Technologies Program set a goal to reach net zero energy buildings by 2025 (European Parliament 2010, Pratsch 2006). Some analyses show that ZEBs already built in the USA between 2002 and 2004 are performing well but do not currently meet federal procurement guidelines for payback periods (Pratsch 2006). Bigger up-front investments are to be seen as one of the largest barriers that net zero energy buildings will face in the market place (Baden 2006).

Though ZEB could be seen as a timely solution of energy savings and ZEB Directives/Programs – a right political will, ZEB concept realization does not ensure implementation of the principle of irreproachableness. This principle is an ethical concept and in a holistic long-life approach to the built environment and its impact on the nature and mankind it requires more efforts, because there are more opportunities to save energy in building sector with less impact on the environment and nature and human health while constructing, using and disposing buildings. ZEB concepts do not focus on embodied energy/embodied carbon (total primary energy consumed/carbon released over a life cycle of the

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building material (Hammond 2008) or on environmental impact of construction materials and processes, as well as safe indoor microclimate for users (for example, do not propose how to avoid sick building syndrome (Passarelli 2009, US EPA 1991, Burge 2004).

The part of embodied energy in the total energy use of a building during its life cycle differs depending on energy efficiency of a building and used construction materials (Hernandez 2010). For example, embodied energy of a low energy apartment housing in Sweden (45 kWh/m2) in a life span of 50 years accounted for 45% of the total energy need (Thormark 2002). As for residential and office buildings with high energy needs – 150-550 kWh/m2 per year, operating energy accounted 80-90% and embodied energy – 10-20% as shown in the survey of 73 cases across 13 countries (Ramesh 2010). The example of a climatically responsive building in the Negev desert region of southern Israel shows that embodied energy of the building accounted for 60% of the overall life-cycle energy consumption (Huberman 2008). Also embodied emissions will account for a high proportion of life cycle emissions for structures which have low occupancy rates (Acquay 2011).

It is possible to recover embodied energy through recycling (Thormark 2002); another option is to use building materials with less embodied energy for construction. Several studies have shown that use of low energy materials could reduce embodied energy by 30-50% (Reddy 2003, Shukla 2009). Hereby, there are proposals to extend ZEB concept, for example to LC-ZEB (Hernandez 2010), but there are also doubts if ZEB is a right solution: for example, in the study of Ramesh it is observed that in the life cycle context low energy buildings perform better than self-sufficient (zero operating energy) buildings (Ramesh 2010).

Reduction in energy needs for both operating of a building and production of building materials, also reduction of risks for people health and ecosystems and lowering up-front investments could make ZEB more attractive and more valuable for the society.

The main aim of this study was to estimate embodied energy and embodied carbon reduction when using straw bale wall construction comparing with traditional construction materials and to analyze possibilities to go beyond ZEB concept.

2. Straw bales – sustainable building material

Straw bale construction history started with the invention of a bailing machine. Baling process provides straw with qualitative new properties compared to loose straw. These new qualities were noticed by farmers when straw bale construction was discovered in the 19th century in Nebraska (USA). Some of still standing straw bale buildings count nearly 100 years of history (Minke 2005). Technology is still under development, because of improvements in agricultural, constructional techniques and new requirements for buildings.

Main advantages of straw bale construction are good thermal insulation properties and reduction in environmental impact to both the nature and the man (renewable, biodegradable waste material in combination with earth or clay plaster maintains healthy indoor microclimate), see some examples of straw bale building in Figs.1-3.

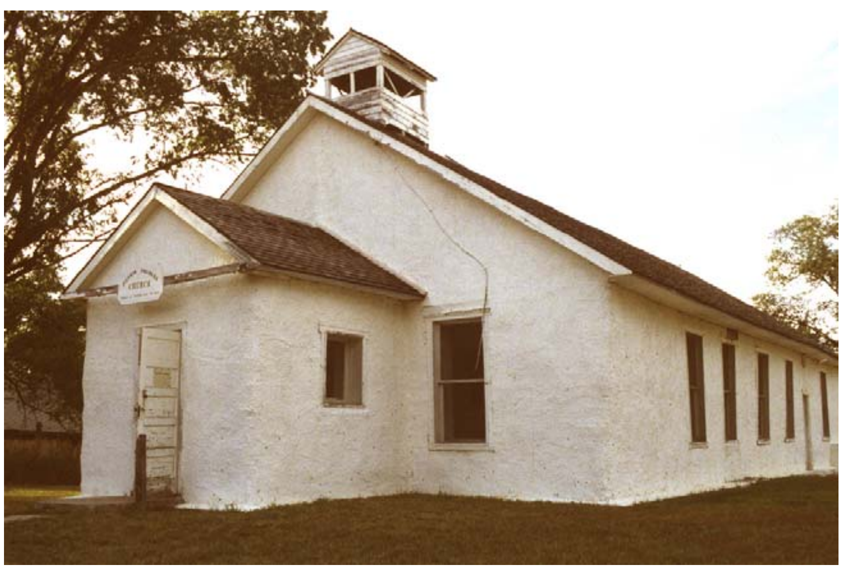

Fig. 1. Pilgrim Holiness Church in Arthur, Nebraska, built in 1928. Photo by Catherine Wanek

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Fig. 2. *Ecocommunity building in Germany. Embodied energy of this building is 5% of the embodied energy of s tandard house building in Germany (Joubert 2006). Photo by Edita Milutiene*

Fig. 3. *Straw bale house under construction. Photo by Arturas Gobys*

Straw as a waste material of cereal production is available in most of the countries all over the world (FAOSTAT 2009, US DA 2010, US DA 1994). It is cheap (compared to building materials); but constructions are rarely "nearly zero money buildings" because of bigger amount of hand work.

In 1990-2000 several research studies were carried out in Denmark, the USA, Germany, Austria, Belarus, the UK analyzing load bearing capacities, thermal properties of straw bales, also fire resistance, moisture contents, durability, etc. (Bainbridge 1986, Weiss 1996, Wimmer 2001, Henderson 2006). Having proved that straw bales are a valuable building material, numerous researches were carried on focusing on moisture content of straw, energy efficiency of straw bale buildings, natural plastering methods of straw, carbon footprint reduction in straw bale buildings (Goodhew 2004, Taylor 2006, Wieland 2002, Wimmer 2001, Shukla 2009, Carfrae 2011, Lawrence 2009).

Historically, straw bale construction started as a load bearing construction (Nebraska style), and further up till now it is being developed depending on users' needs, construction presses improvement and new agriculture techniques. Main methods to build with straw are: load bearing construction, frame construction, panel construction and load bearing construction from big bales. All of them have different advantages, see Table 1.

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Table 1. Straw bale construction methods

Construction method	Construction time	Resources (materials)	Cost	Description
Load bearing	**	*	*	The oldest method; estimated like the simplest method to build with straw bales; the cheapest because of reduction in timber use; has limitations when using for bigger than 1.5 storey buildings (Fig. 4).
Frame	***	**	**	Wood, bricks, metal and other materials could serve as a frame; straw bales are used as infill, thus buildings could be 3, 4 storey and higher; the price rises because of using frame materials and frame construction (this needs professional qualifications); less sensitive to the weather at the construction site (Fig.5).
Panel	*	***	***	Fast assemblage on site (prefabrication indoors); use of additional materials to make panels requires professional skills (Fig. 6).
Load bearing, big bales	*	**	**	Fast assemblage on site (bales are carried with tractor); better thermal insulation of a building; bigger buildings without frame (compared to load bearing); more problems to smooth walls; more problems to plaster walls (Fig. 7).

Fig. 4. Load bearing construction, Belgium. Photo by Edita Milutiene

Fig. 5. Frame construction, Belgium. Photo by Edita Milutiene

Fig. 6. Panel construction, Lithuania. Photo by JSK Ecococon

Fig. 7. Construction using big bales, Denmark. Photo by Lars Keller

Communities in Europe, the USA, Mongolia and other places could solve socioeconomic problems when using straw and other local resources for construction (UNDP 2007, WHA 2007, Zhu 2005, Worldwatch Institute 2010).

There are several problems in straw bale building: straw/straw bales/straw bale walls should be protected from direct rain and straw bale walls should be constructed avoiding gaps. These problems are solved by improvement in construction technologies and scrupulous work.

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3. Embodied energy and embodied carbon comparison of masonry and straw bale construction

There are several openly available inventories of embodied energy of building materials. Data on these inventories differ depending on boundary conditions (cradle to gate/cradle to site) and fuel mix of the country in which analysis is performed.

One of the tools which could be used to evaluate embodied energy of constructions is the Inventory of Carbon and Energy (ICE), introduced by Geoff Hammond and Craig Jones (Hammond 2008a, Hammond 2008b). ICE is based on data collected from secondary resources in the public domain.

Aiming to estimate embodied energy and embodied carbon reduction when using straw bale wall construction instead of traditional masonry construction, there was chosen construction element – 1 m2 of a wall with thermal resistance 8 m² K/W, see Table 2.

For the evaluation of carbon footprint reduction, replacing traditional building materials with renewable and local building materials (Table 2), a simple masonry construction (wall assemblage of clay bricks, stone wool and plastering with gypsum plaster also painted) was analyzed.

Data of straw bale construction assemblies and materials were received during theoretical studies of straw bale construction load bearing and frame construction methods also from practical work in straw bale building seminars in several countries (Lithuania, Germany, the UK, Belgium) during implementation of the project "Promotion of Straw Bale Building for the Climate Change Mitigation" (Milutiene 2007, Milutiene 2008).

Data of straw bale panel construction method were received from JSK "Ecococon", which is developing straw bale building in Lithuania, mainly panel and frame construction methods.

There were some limitations to make estimations of straw bale construction, because the Inventory of Carbon and Energy (ICE) does not include information about raw materials like clay. Straw bales are considered an agricultural product, and this provides another result, when straw is analyzed as waste material.

Estimations have shown that chosen construction methods differ when comparing embodied energy and embodied carbon (Table 2.). Total embodied energy of masonry wall is 1429.69 MJ/m2, that of embodied carbon – 105.32 kg CO2/m2. Total embodied energy of straw bale wall (frame construction) is 202.61 MJ/m2, that of embodied carbon – 15.99 kg CO2/m2, total embodied energy of straw bale wall (load bearing construction) is 74.84 MJ/m2, that of embodied carbon – 3.98 kg CO2/m2. Differences between calculated values differ from 7 (comparison of embodied energy of masonry and straw bale frame constructions) to 26 times (comparison of embodied carbon of masonry and straw bale load bearing constructions).

Table 2. Materials, assembles of 1 m2 wall of masonry and straw bale wall construction

Wall element	Embodied energy, MJ	Embodied carbon, kg CO2	MATERIALS/ ASSEMBLIES	Amount	Unit	Embodied energy, MJ/kg	Embodied carbon, kg CO2/kg
Masonry construction							
Constructio n	1188.43	90.49					
	1125.00	82.50	General Clay Bricks	375.00	kg	3.00	0.22
	62.23	7.99	Mortar (Cement: Lime: Sand 1:1:6)	49.00	kg	1.27	0.16
	1,20	0.00	Water	6.00	kg	0,20	
Thermal insulation	168.00	10.50	Rock wool	10.00	kg	16.80	1.05
Fastening	2.42	0.08	General plastics	0.03	kg	80.50	2.53
Finish	70.84	4.25					
	40.32	2.69	General plaster	22.40	kg	1.80	0.12
	0.60	0.00	Water	3.00	kg	0.20	
	29.92	1.57	General paint	0.44	kg	68.00	3.56
Total	1429.69	105.32					
Straw bale construction (frame construction)							
Constructio n	113.22	6.89	Sawn softwood timber	15.30	kg	7.40	0.45
Thermal	11.28	0.47	Straw	47.00	kg	0.24	0.01

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Wall element	Embodied energy, MJ	Embodied carbon, kg CO2	MATERIALS/ ASSEMBLIES	Amount	Unit	Embodied energy, MJ/kg	Embodied carbon, kg CO2/kg
insulation							
Fastening	0.98	0.07	General steel	0.04	kg	24.40	1.77
Finish	77.13	8.57					
	18.45	0.94	General (rammed) soil	41.00	kg	0.45	0.02
	4.48	0.22	General sand	44.80	kg	0.10	0.01
	.1.20	0..00	Water	6.00	kg	0.20	
	53.00	7.40	General lime	10.00	kg	5.30	0.74
Total	202.61	15.99					
Straw bale construction (load bearing construction)							
Construction	33.97	2.07	Sawn softwood timber	4.59	kg	7.40	0.45
Thermal insulation	12.00	0.50	Straw	50.00	kg	0.24	0.01
Fastening	0.24	0.02	General steel	0.01	kg	24.40	1.77
Finish	28.63	1.40					
	22.95	1.17	General (rammed) soil	51.00	kg	0,45	0.02
	4.48	0.22	General sand	44.80	kg	0.10	0.01
	1.20	0.00	Water	6.00	kg	0.20	
Total	74.84	3.98					

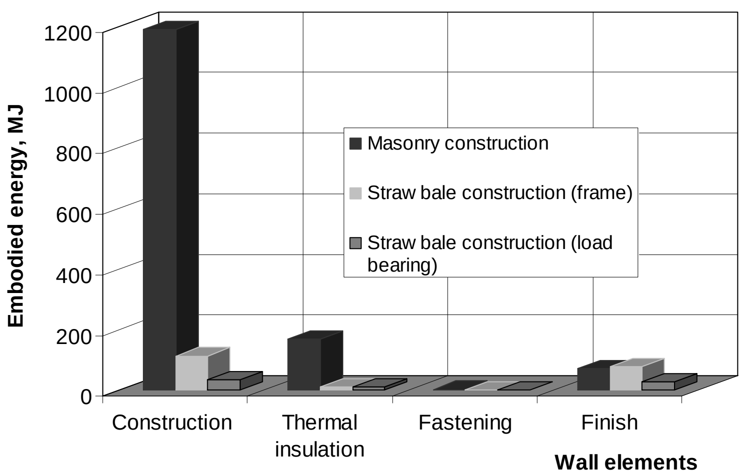

Fig. 8. Embodied energy of masonry and straw bale construction

The biggest difference in embodied energy and carbon is estimated because of used different construction materials (Figs 8 and 9). To produce bricks and mortar which contain cement a lot of energy is used. As for straw bale construction, use of timber for the frame increases embodied energy and carbon of construction element. Use of lime in plaster raised the value of embodied energy and embodied carbon of straw bale construction. Lime use in a plaster is not necessary and it is not connected with a construction method (load bearing, frame, or other) – it is just a case of plaster which contains local natural resources and has good properties. In this estimation load bearing construction example includes simpler plaster than a frame construction example (without lime).

When analyzing which wall elements make the biggest impact to embodied energy values, the study of (Dimoudi 2008) has shown that construction materials, such as concrete and reinforcement steel had the biggest embodied energy of the examined buildings and varied from 60% to 67%.

In the analyzed examples of this research the embodied energy of construction material is 83% in

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masonry construction and it is 56% in straw bale building frame construction. Plastering of straw bale wall accounts for 38% of embodied energy when it contains lime. As shown in estimations of straw bale wall load bearing construction, possibilities remain to continue reducing the embodied energy using less timber and avoiding lime.

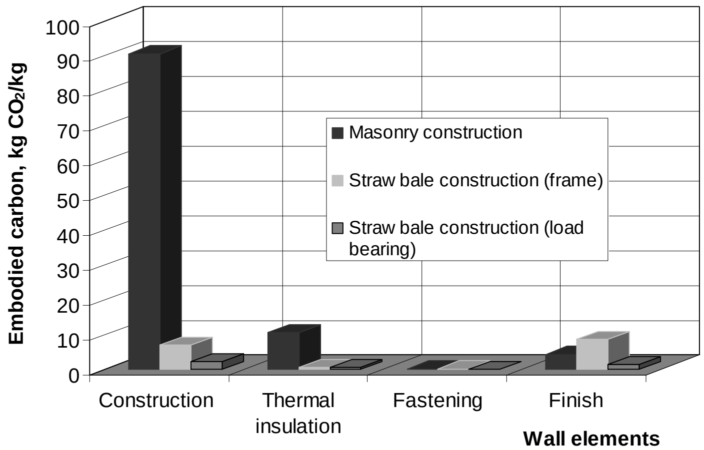

Fig. 9. Embodied carbon of masonry and straw bale construction

In panel construction (Table 3), a part of timber is replaced with plywood, this increases embodied energy and embodied carbon of a wall (from 46.21 MJ/m2 in load-bearing, and from 125.48 MJ/m2 in frame construction to 144.47 MJ/m2) and it also provides straw bale construction with new properties and technological application possibilities (fast assemblage on site, possibilities to prefabricate indoors).

Table 4 shows possible savings of embodied carbon for one family house construction. Changing the wall construction from masonry to straw bale frame construction it is possible to save 12-14 t of CO2.

Table 3. Embodied energy and embodied carbon of straw bale panel construction for 1 m2 of wall

Wall element	Embodied energy, MJ	Embodied carbon, kg CO2	MATERIALS/ ASSEMBLIES	Amount	Unit	Embodied energy, MJ/kg	Embodied carbon, kg CO2/kg
Straw bale construction (panels)							
Construction	129.97	7.74					
	105.67	6.43	Sawn softwood timber	14.28	kg	7.40	0.45
	24.30	1.31	Playwood	1.62	kg	15.00	0.81
Thermal insulation	11.52	0.48	Straw	48.00	kg	0.24	0.01
Fastening	0.98	0.07	General steel	0.04	kg	24.40	1.77
Total (without finish)	142.47						

Table 4. Embodied carbon saving possibilities for one and a half storey house with the perimeter of 36 m. area of 160 m^2

Wall construction method	Embodied energy of wall, MJ/m2	Embodied carbon, kg CO2/m2 of wall	Embodied energy of house walls, MJ	Embodied carbon of house walls, t CO2	Savings, t CO2
Masonry construction	1429.69	105.32	197297.22	14.53	
Straw bale construction (frame)	202.61	15.99	27960.18	2.21	12.33
Straw bale construction (load bearing)	74.84	3.98	10327.92	0.55	13.98

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Straw bale construction provides possibilities to lower carbon footprint of buildings in a sustainable way. Various construction technologies (load bearing, frame, panel) allow renewable local resources to be used for straw bale construction for different purposes (residential, commercial, social buildings or other).

4. Conclusions

Straw bale construction proved its durability and suitability for low energy houses or even ZEB or Zero carbon buildings. Straw bale construction could be seen as harmonious and efficient way of the use of local resources.

Embodied energy and embodied carbon calculations show that straw bale construction is less harmful to the environment compared to masonry construction. Differences between calculated values vary from 7 (embodied energy of masonry and straw bale frame constructions) to 26 times (embodied carbon of masonry and straw bale load bearing constructions). Constructing a straw bale building could save 12-14 t of CO2 emissions compared to masonry construction.

ZEB concepts do not focus on environmental impact of construction materials and processes or on safe indoor microclimate for users. ZEB has also additional investment costs. Use of natural building materials: straw bales, earth, clay, etc. could make ZEB more attractive and more valuable for the society in terms of ecology, health and finances.

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References

ACQUAYE, A., Duffy, A., Basu, B. Embodied emissions abatement – a policy assessment using stochastic analysis. Energy Policy, 2011, Vol. 39, No. 1. pp. 429-441.

BADEN, S. et al. 2006. Hurdling Financial Barriers to Lower Energy Buildings: Experiences from the USA and Europe on Financial Incentives and Monetizing Building Energy Savings in Private Investment Decisions. Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings. American Council for Energy Efficient Economy. Washington DC, August 2006. [2010-10-1]: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-396-06.pdf.

BAINBRIDGE, D. A. High performance low cost buildings of straw. Agriculture. Ecosystems & Environment, 1986, Vol. 16, No. 3. pp.281-284.

BURGE, P. S. Sick Building Syndrome. Occupational and Environmental Medicine, 2004, Vol. 61. pp. 185-190. [2010-10-10]: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1740708/pdf/v061p00185.pdf.

CARFRAE, J., De Wilde, P., Littlewood, J., Goodhew, S., Walker, P. Development of a cost effective probe for the long term monitoring of straw bale buildings. Building and Environment, 2011, Vol. 46, No. 1. pp. 156-164.

DIMOUDI, A., Tompa, C. Energy and environmental indicators related to construction of office buildings. Resources. Conservation and Recycling, 2008, Vol. 53, No. 1-2, pp. 86-95.

DRACK, M., Wimmer, R., Hohensinner, H. Treeplast Screw – a device for mounting various items to straw bale constructions. The Journal of Sustainable Product Design, 2004,Vol. 4, No. 1-4. pp. 33-41.

EUROPEAN PARLIAMENT. Directive 2010/31/Eu Of The European Parliament and of The Council of 19 May 2010 on the energy performance of buildings (recast). [2010-09-03]: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ%3AL%3A2010%3A153%3A0013%3A0035%3AEN%3APDF.

Food And Agriculture Organization Of The United Nations. FAOSTAT 2009. Crops. [2010-09-03]: http://faostat.fao.org/site/567/default.aspx#ancor.

FORSCHUNGSINSTITUT FUR WARMESCHUTZ e.V. Munchen. Warmeleitfahigkeit nach DIN 52612 (2003). [2010-09-03]: http://www.downloads.fasba.de/oeffentlich/pruefzeugnisse/pb-lambda.pdf.

GOODHEW, S., Griffiths, R., Woolley, T. An investigation of the moisture content in the walls of a straw-bale building. Building and Environment, 2004, Vol. 39, No. 12. pp. 1443–1451.

HAMMOND, G. P., Jones, C. I. Embodied energy and carbon in construction materials. Proceedings of the ICE-Energy, 2008, Vol. 161, No. 2. pp. 87-98. ISSN: 1751-4223. E-ISSN: 1751-4231.

HAMMOND, G. P., Jones, C. I. Inventory of Carbon & Energy. 2008. [2010-09-03]: https://wiki.bath.ac.uk/display/ICE/Home+Page.

HENDERSON, K. Ethics. Culture and Structure in the Negotiation of Straw Bale Building Codes. Science, Technology & Human Values, 2006, Vol. 31, No 3. pp. 261-288.

HERNANDEZ, P., Kenny. P. From net energy to zero energy buildings: defining life cycle zero energy buildings (LC-ZEB). Energy and Buildings, 2010, Vol. 42. pp. 815-821.

HUBERMAN, N., Pearlmutter, D. A life-cycle energy analysis of building materials in the Negev

#

desert. Energy and Buildings, 2008, Vol. 40, No. 5. pp. 837-848.

JOUBERT, K., Schimmel, U. Ecovillage lobbying sees strawbale building legalised in Germany. 2007. [2010-10-03]: http://www.gen-europe.org/activities/newsletters/12_2006.html.

LAWRENCE, M., Heath, A., Walker, P. Determining moisture levels in straw bale construction. Construction and Building Materials, 2009, Vol. 23, No. 8. pp. 2763-2768.

MILUTIENĖ, E., Jurmann, K., Keller, L. Straw Bale Building – Reaching Energy Efficiency and Sustainability in Northern Latitudes. Abstract Book of 11th International conference on Solar Energy at High Latitudes "North Sun 2007", Riga, 30th May-1st June, 2007. pp. 38–39.

MILUTIENĖ, E., et al. 2008. Šiaudiniai namai (Straw bale houses, in Lithuanian). ATEIK, Vilnius, Lithuania, p. 256. pp. ISBN 978-9955-9778-5-8.

MINKE, G., Mahlke, F. 2005. Building with Straw. Design and Technology of a Sustainable Architecture. Birkhouser, Basel, Berlin, Boston, p. 146. pp. 13-24, 138. ISBN 3-7643-7171-4.

National Renewable Energy Laboratory Research Center (NREL RC). 2006. The potential impact of Zero energy homes. [2010-08-01]: http://www.toolbase.org/pdf/casestudies/zehpotentialimpact.pdf.

PASSARELLI, G. R. Sick building syndrome: An overview to raise awareness. Journal of Building Appraisal, 2009, Vol. 5. pp. 55-66.

PRATSCH, L. W. On the Path to Zero Energy Homes. 2006. [2010-08-01]: http://www.netzeroenergyhome.ca/Files/files/research/Zero-Energy_Pratsch.pdf.

RAMESH, T., Prakash, R., Shukla, K.K. Life cycle energy analysis of buildings: An overview Review Article. Energy and Buildings, 2010, Vol. 42, No. 10. pp. 1592-1600.

REDDY, Venkatarama B.V., Jagadish K.S. Embodied energy of common and alternative building materials and technologies. Energy and Buildings, 2003, Vol. 35, pp. 129-137.

SHUKLA, A., Tiwari, G.N., Sodha, M.S. Embodied energy analysis of adobe house. Renewable Energy, 2009, Vol. 34. pp. 755-761.

TAYLOR, B., Vardy, S., MacDougall, C. Compressive Strength Testing of Earthen Plasters for Straw Bale Wall Application. Advances in Engineering Structures. Mechanics & Construction, 2006, Vol. 140. pp. 175-183.

THORMARK, C. A low energy building in a life cycle – its embodied energy, energy need for operation and recycling potential. Building and Environment, 2002, Vol. 37. pp. 429- 435.

TORCELLINI, P., Pless, S., Deru, M., Crawley, D. Zero Energy Buildings: A Critical Look at the Definition. Preprint. ACEEE Summer Study Pacific Grove. California, USA, August 14–18. 2006. NREL/CP-550-39833. [2010-09-03]: http://www.nrel.gov/docs/fy06osti/39833.pdf.

UNDP Regional Centre in Bangkok. East Asia: Energy-Efficient Straw-Bale Housing in Mongolia. 2002-2007. [2010-09-03]: http://content.undp.org/go/cms-service/stream/asset/?asset_id=2095743.

United States Environmental Protection Agency (US EPA). 1991. Indoor Air Facts No. 4 (revised) Sick Building Syndrome. [2010-11-15]: http://www.epa.gov/iaq/pdfs/sick_building_factsheet.pdf.

US DA Office of Global Analysis. Wheat Production 2010/2011. [2010-11-15]: http://www.pecad.fas.usda.gov/ogamaps/default.cfm?cmdty=Wheat&attribute=Production.

US DA World Agricultural Outlook Board. 1994. Agricultural Handbook No. 664. Major World Crop Areas and Climatic Profiles. [2010-09-03]: http://www.usda.gov/oce/weather/pubs/Other/MWCACP/MajorWorldCropAreas.pdf.

US Department of Energy (US DE). Energy Savings from Small Near-Zero-Energy Houses. 2007. [2010-09-03]: http://www1.eere.energy.gov/femp/pdfs/tir_zeroenergyhouses.pdf.

WEISS, J., Stone, L. Houses of straw. Fuel and Energy Abstracts, 1996, Vol. 37, No. 3. pp. 214.

WIELAND, H., Ashour, T., Bockisch, F. J. Straw – Renaissance for an Old Building Material. Landtechnik, 2002, Vol. 57, No 4. pp. 222-223.

WIMMER, R., Hohensinner, H., Janisch, L., Drack, M. Wandsysteme aus nachwachsenden Rohstoffen. 2001. [2010-11-03]: http://www.grat.at/Publikationen/Wandaufbau_aus_NWR.pdf.

WORLDWATCH INSTITUTE. State of the World Transforming Cultures from Consumerism to Sustainability. 2010. [2010-09-03]: http://www.gaiaeducation.org/docs/Ecovillages%20Transformation%20Values.pdf.

World Habitat Awards (WHA) 2007. Straw-bale Housing in the Sieben Linden Ecovillage. [2010-09-03]: http://www.worldhabitatawards.org/winners-and-finalists/project-details.cfm?lang=00&theProjectID=740B4CEF-15C5-F4C0-99FC9EA83F00FB5C.

ZHU, L. Straw Bale Ecological Housing Program. The Second International Conference on Gross National Happiness "Rethinking Development: Local Pathways to Global Wellbeing" St. Francis Xavier University. Antigonish. Nova Scotia, Canada, June 20-24, 2005. [2010-09-03]: http://www.gpiatlantic.org/conference/papers/zhu.pdf.

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Kauno technologijos universitetas. Aplinkos inžinerijos institutas

(gauta 2010 m. gruodžio mėn.; atiduota spaudai 2010 m. gruodžio mėn.)

Siekiant sumažinti statybų poveikį klimato kaitai, neišvengiami radikalūs šio sektoriaus pokyčiai, kadangi vien pastatams išlaikyti suvartojama 40 % pirminės energijos, pagaminamos Europos Sąjungoje ir kitose šalyse. Statyba taip pat neigiamai veikia aplinkos kokybę, daro įtaką klimato kaitai ir dėl statybinių medžiagų gamybos. Nulinės energijos pastatų koncepcija sujungia energijos efektyvumą, energijos taupymą ir atsinaujinančių energijos išteklių naudojimą pastato eksploatacijos metu. Ši koncepcija būtina siekiant pakeisti dabartinę situaciją, tačiau turi ir trūkumų – joje atsispindi ne visos darnios statybų sektoriaus plėtros galimybės. Straipsnyje analizuojamos įkūnytosios energijos ir įkūnytosios anglies sumažinimo galimybės, kai šiaudų ryšuliai ir kitos vietinės medžiagos naudojamos sienų gamybai. Tyrimai parodė, kad pakeitus laikantį sienos komponentą, t. y. plytas, mediena, o šilumos izoliaciją, t. y. akmens vatą, šiaudų ryšuliais, sienos įkūnytąją energiją galima sumažinti daugiau nei 7 kartus. Kadangi presuotų šiaudų ryšulių šilumine varža didesnė nei norminė, jie gali būti naudojami pasyviesiems pastatams statyti ar nulinei energijos pastato koncepcijai įgyvendinti. Kartu presuotų šiaudų ryšuliai gali padėti išvengti žalos, kuri atsirastų naudojant šiluminę izoliaciją, pagamintą ne iš vietinių atsinaujinančių žaliavų.

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