Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 96 (2016) 323 – 332

Energy Procedia

SBE16 Tallinn and Helsinki Conference; Build Green and Renovate Deep, 5-7 October 2016, Tallinn and Helsinki

LIFE Cycle Habitation - Designing Green Buildings

Robert Wimmer[a]*, Sören Eikemeier[a], Anita Preisler[b] and Michael Berger[b]

[a]*GrAT - Center for Appropriate Technology, Vienna University of Technology, Wiedner Hauptstraße 8-10, 1040 Vienna, Austria*
[b]*teamgmi Ingenieurbüro GmbH, Schönbrunnerstrasse 44/10, 1050 Vienna, Austria*

Abstract

The overall goal of the EU project "LIFE Cycle Habitation" is to design and build prototypes for carbon-neutral and "LIFE cycle"-oriented buildings to make energy-efficient settlements the standard of tomorrow in line with the EU 2020 objectives. Therefore 7 residential units of different types and styles and a community centre are designed in an integral planning approach to demonstrate highly resource and energy-efficient prototype buildings in Böheimkirchen, Lower Austria.

Peer-review under responsibility of the organizing committee of the SBE16 Tallinn and Helsinki Conference.

Keywords: Sustainable Building; Renewable Resources; Energy-efficiency; Building Simulation; Innovative Energy Concept

1. Introduction

A relatively large percentage of energy and resource consumption occurs in the building sector [1]. This concerns the production of building materials, the construction of buildings and also the energy consumption during the use phase caused by the users. Energy for space heating and increasingly for space cooling is needed especially for buildings of low energy standard. Furthermore, energy for domestic hot water and appliances (like cooking stove, washing machine, light and other electrical devices) is required. During the life cycle of buildings additional energy and resource consumption is caused by demolition and disposal of buildings or building parts at the end of their lifetime.

* Corresponding author. Tel.: +43-1-58801-49523; fax: +43-1-58801-49533.
E-mail address: contact@grat.at

Peer-review under responsibility of the organizing committee of the SBE16 Tallinn and Helsinki Conference.
doi:10.1016/j.egypro.2016.09.155

With its high consumption of energy and thus mostly fossil fuels for the majority of processes, the building sector is also one of the biggest perpetrators of CO_2 emissions. In addition, it produces construction waste as a consequence of demolition or remodelling of buildings as well as at the construction site (packaging, plastic pipes, clippings of insulation materials etc.), which is difficult to recycle or dispose of. The aspects of deconstruction, recycling and disposal were particularly highlighted in Austria due to a massive increase of building waste in the last years [2]. Although, according to the "Federal Waste Management Plan 2011" by the Ministry of Life [3], the total amount of waste decreased by 500,000 t to 53,543,000 t, waste from the building sector still accounts for 12.7 % of total waste in Austria (6,870,000 t). A prognosis for 2016 foresees an increase to 7,395,000 t.

The demand for alternative solutions is also stated by a recently introduced supplementary document in addition to the waste framework directive 2008/98/EG, which supports the goal of a minimum recycling rate of 70 % of non-hazardous construction and demolition waste until 2020 [4]. This document also includes duties for the demolition of buildings approved after the 1st of January 2016 regarding the separation of materials to prepare for the re-use of high-quality recycling materials.

The overall objective of the EU project "LIFE Cycle Habitation" is therefore to demonstrate innovative building concepts that significantly reduce CO_2 emissions, mitigate climate change and contain a minimum of grey energy over their entire life cycle. The ultimate goal is to design and build prototypes for carbon-neutral and "LIFE cycle"-oriented residential buildings and make energy-efficient settlements the standard of tomorrow in line with the EU 2020 objectives. To this end, a highly resource and energy-efficient building compound is being built in Böheimkirchen, Lower Austria, consisting of 7 residential units and a community centre.

2. Method

The assessment of building components usually considers criteria such as insulation effect, absence of thermal bridges and, on the part of consumers, costs for the selection of materials. Constructions with sufficient insulation and no thermal bridges can be achieved with various materials, if building physics are considered and implementation is done carefully. Ecological assessment of different building materials, however, yields varying results. A comprehensive ecological assessment requires consideration of the whole life cycle.

The concept of Life Cycle Habitation (see Fig. 1) is therefore based on energy-efficient building solutions (passive house components, improved household appliances, thermal insulation etc.) and on the utilization of regionally available renewable resources for building materials to reach a lower energy demand in production as well as shorter transport distances. In addition to this, deconstruction is considered from the planning process on to promote recycling and composting after the use period. For further reduction of the carbon footprint it is also necessary to have an energy system using locally available renewable resources.

To reach these goals, solutions in three strands, which were developed in prior research projects, are further evolved and implemented so as to reduce CO_2 emissions and to decrease waste of resources significantly over the entire life cycle:

- Highly energy-efficient and sustainable building materials are used: straw bales are regional renewable resources with very low "grey energy"; they store CO_2 and provide high thermal insulation.
- Innovative construction types: load-bearing as well as pre-fabricated modular building elements are produced by local SMEs (Small and Medium Enterprises) that are efficiently coordinated [5].
- Energy supply: the thermal and the electrical energy demand are supplied by renewable energies with a focus on solar energy and biomass [6].

For merging these innovations into an overall concept a number of state-of-the-art tools for architecture, civil engineering and building simulation are used.

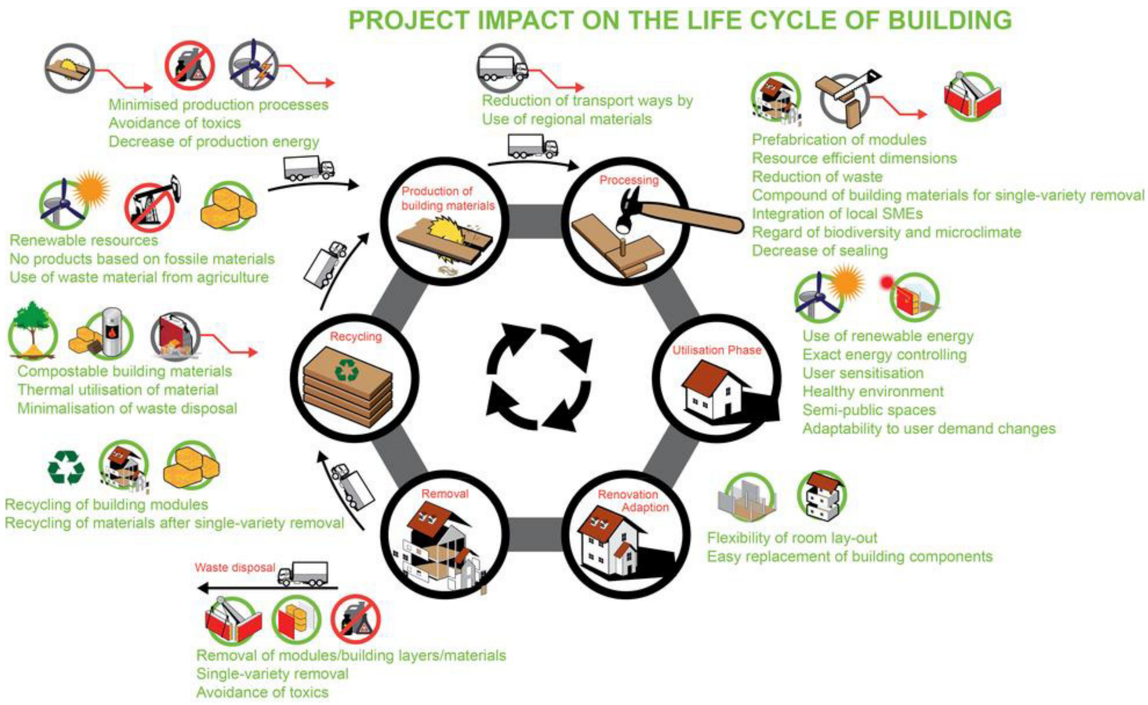

Fig. 1. Project impact on the life cycle (GrAT).

3. Sustainable Building Materials and Constructions

3.1. Assessments

Assessments and quality control of buildings can be executed on different levels and with various foci. In general, international building rating programs are used, such as LEED, BREAM or WBS in Switzerland and in Austria specifically the mandatory assessment instrument *Energieausweis* (energy certificate), which is an indicator computing the energy demand per m^2 and year in accordance with national and European laws [7].

The assessment of building materials is a sensitive topic, because a large range of different materials is available for building owners and planners. In order to choose the most appropriate, a number of technical and environmental factors have to be considered. Building materials should be non-polluting, have warm surfaces, be humidity balancing, capable of sorption, have pleasant smell, low radioactive radiation, and show high haptic quality [8]. These criteria are considered in the Life Cycle Habitation project, while eminent values of technical parameters like heat conductivity, heat storage capacity, reaction to fire, vapour diffusion resistance, sound insulation or dimensional stability are pre-conditions for the selection of the materials to be used for the different parts of the buildings. For further improvement of the environmental impact a low PEI (primary energy demand of non-renewable resources) in MJ/kg and a low or negative GWP (Global Warming Potential) in kg CO_2/kg as well as AP (Acidification Potential) in kg SO_2/kg is required. Based on these values the ecological indicator OI3 can be calculated for an ecological assessment of the materials for buildings with different system boundaries, as shown by the guideline prepared by IBO (Austrian Institute for Healthy and Ecological Building) [9].

For the Life Cycle Habitation project situated in Austria the TQB (Total Quality Building) assessment tool of the ASBC (Austrian Sustainable Building Council) is being used as general rating program for the prototype buildings, which is covering the categories site, infrastructure and architectural quality, economics and technical quality, energy and supply, healthiness and comfort as well as resource efficiency in a comprehensive assessment approach including both the *Energieausweis* and the ecological indicators PEI, GWP, AP and OI3 [10].

3.2. Renewable resources

Highly energy-efficient and sustainable building materials based on renewable resources, such as straw bales, which play a key role in this project, have been proven to be functional, and show a very low PEI and positive effect for the CO_2 balance of the building [11]. With the Austrian Technical Approval (ÖTZ) in 2010 [12], the functionality of straw bales as an insulation material has been certified [13]. This includes the application in loadbearing as well as in non-loadbearing constructions. Because of the simple production process (the raw material straw only needs to be pressed and tied up) the production energy of straw bales is by a factor of 100 lower in comparison to conventional insulation materials, comparing wall constructions with the same heat transfer resistance, which is the most important feature of insulation materials, see Fig. 2 (a). A comparison of the GWP of these insulation materials is showing a similar positive environmental effect. While fossil or mineral-based materials are releasing huge amounts of CO_2 during the production process, materials made of renewable resources, on the contrary, are able to store large amounts of CO_2, see Fig. 2 (b).

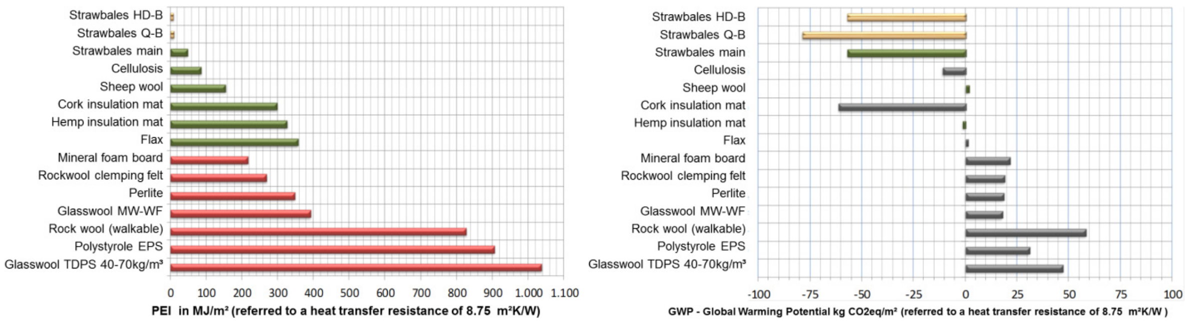

Fig. 2. (a) PEI of different insulation materials (GrAT); (b) GWP of different insulation materials (GrAT).

The involvement of local stakeholders, especially small and medium-sized enterprises, and the local availability of the materials is a core aspect in order to reduce the energy demand for transport and therefore to obtain construction materials with a minimum of grey energy.

3.3. Innovative construction types

There are several variants of wall constructions using wood and straw for prefabricating building elements or entire constructions. Through the strategy of standardized prefabrication combined with an efficient coordination of the participating companies, waste will be reduced to a minimum, as will unnecessary material consumption through design and installation errors. In industrial prefabrication, manufacturing processes of building components and modules are standardized so that the finished parts are aligned to each other. Therefore the construction time on site can be shortened, waste be reduced and assembly faults be avoided. Prefabrication is possible even for large elements, such as complete bathrooms units or rooms with integrated kitchens. Continuing this modularization should encompass the manufacturing of compatible elements for the building envelope, housing technology as well as appliances.

In this project two different types of wood-straw bale construction will be realized. The first variant, for the building compound, consists of non-load-bearing wall modules which have been prefabricated and filled with the insulation material in the factory. The second variant, for the detached houses, will be made of prefabricated individual elements without insulation material, which will be assembled on the construction site by the involved SMEs. For the second variant, it is possible to prefabricate the elements made of CLT (cross laminated timber) accurately for the components of the façade or the housing technology boxes with a CNC shaper, which then are supplemented on site with the materials straw and clay taken from the immediate vicinity.

For a sustainable and efficient use of raw materials, removal should be based on the cascades principle, thus keeping raw materials and products in a circular economy as long as possible. The utilization cascade consists of single and multiple substance-based utilization with decreasing added value (product and material recycling) and subsequent composting or energetic utilization (thermal utilization). Disposal of materials should only be considered as the last choice. Nowadays, however, many elements consist of composites which are no longer separable. Therefore it is necessary to use detachable connections and fittings, which can already be assembled in the factory. Concerning re-use and recycling possibilities it is important to examine not only materials but to evaluate the entire construction. The degree of recyclability of a construction depends on the properties of the used materials, the mass and cascade of the materials as well as their assembly within the construction. All materials used in the constructions of Life Cycle Habitation can be disassembled and therefore re-used or recycled. The separability and cascades of the used materials are described in Table 1 by taking as example a variation of a non-load-bearing construction type [14].

This ecological evaluation was also applied for the award winning LISI house (Living Inspired by Sustainable Innovation) of the Solar Decathlon 2013 in California, which was designed and constructed by the Team Austria. This concept can also be adopted for variants of loadbearing or partially loadbearing systems – either single construction elements or prefabricated modular units containing domestic engineering, wet cells etc. These can in the best case be interconnected to the core of the building, around which the straw bales (big or small bales) can be placed afterwards for static and thermal reasons, finishing for example with an exterior layer of plaster.

Table 1. Cascade principle for a wood-straw wall element (GrAT).

Material/Parameter	CLT wood	Straw bales	Clay plaster	Wooden laths (timber, planed, tech. dried)	Wooden façade (timber, rough, air dry)
Useful life (years)	100	50	100	60	60
Composting	No	yes (after opening)	yes (if only natural additives)	yes	yes
Product recycling	re-use	re-use (if necessary cutting/tying -> insulation material)	re-use (moistening with water, cleaning -> clay plaster)	re-use	re-use
Material recycling	further use -> e.g. chipboards	further use (opening, if necessary baling) -> straw bales, fertilizer, bedding	further use (moistening with water) -> new clay products	further use -> e.g. chipboards	further use -> e.g. chipboards
Thermal utilization	yes - 18 MJ/kg	yes - 17.5 MJ/kg	not possible	yes - 18 MJ/kg	yes - 18 MJ/kg
Disposal	possible after thermal treatment	possible after thermal treatment	disposal category 3possible (but usually composting)	possible after thermal treatment	possible after thermal treatment
Additives	very small proportions of binder materials (PUR adhesive)	thread (hemp, sisal, PP)	hemp, flax etc. possible	no	no
Regional	Yes	yes	Yes	yes	yes

3.4. Architectural design and site

First results of this ongoing project in addition to the analysis and development of technical components are the design of the site-plan on the selected area in Böheimkirchen, Lower Austria, as well as the preliminary architectural draft of the prototype buildings. The site-plan (see Fig. 3) is divided into 2 sections. The prototype buildings will be constructed on the southern part of the property, while also a scenario for the northern part is included, which will be realized after the end of the project using the developed building concepts as template for replication.

Fig. 3. Site-plan for the project location (Scheicher).

The preliminary architectural design in Fig. 4 is showing the building compound, which is including 5 different building units and a community centre as well as 2 single family houses. The building compound will be designed as a 2-storey non-load-bearing construction innovatively evolved from the neighbouring award winning S-House [15] and is consisting of 2 row houses with a size of 105 m² each, 2 apartments of 60 m².

This demonstrates multi-storey residential buildings, as well as an additional 90 m² apartment and a community centre. The single family houses will be realized as compacted flat-roof buildings with an identical 1-storey load-bearing straw bale construction, but with a different housing technology concept. In total, building units with a usable floor surface of approximately 710 m² will be put up and optimized in terms of energy-efficiency.

Regarding the evaluation with the assessment tool of the ASBC, an analysis of the project location was carried out in an early stageof the planning phase. This concerns infrastructure including public transport, quality of local supply and social infrastructure, recreation areas and facilities as well as the security of the site and the quality of the building land with the subcategories risk of natural hazards, sealing of the site, interferences by low frequencies and others transmitters. For these categories the maximum points of 100 are achieved showing that the selected site is perfectly qualified for the realization of the project.

Fig. 4. Preliminary draft of the prototype buildings (Scheicher).

4. Energy Concept

4.1. Energy-efficiency

The demand for electricity keeps rising in private households of EU-27 countries, despite increasingly energy-efficient devices. From 1999 to 2009 demand has risen by 18.5 % [16] with an ongoing trend. New resource-efficient energy concepts using renewable energy sources are needed. In conventional energy systems in households, most appliances are operated mainly by electricity although they actually provide thermal energy services. In contrast to this, the energy concept for the prototype buildings in this project is based on the maximum utilization of thermal energy gained from solar energy and biomass. All thermal appliances such as washing machine, dishwasher or dryer are operated by thermal energy in addition to providing energy for hot water and heating. Based on the idea of an indirectly operated solar cooker using thermal oil as a heat transfer medium [17], an optimized prototype version was developed for the Zero Carbon Resorts Demonstration Cottage [18] and will be implemented in the community centre after further adaption, while cooking for the living units is provided by biogas. This new version of the cooker can also be equipped with a connection facility for a refrigerator and a freezer, which too require a higher temperature level when operated with thermal energy [19]. By consistently considering the required form of energy and the use of the most appropriate technologies, it should be possible, based on the energy balance (input/output), to reduce the consumption of electric energy by up to 80 % to approximately 675 kWh/a, compared with the median consumption of Austrian households of 3934 kWh/a [20].

4.2. Energy supply

For the layout of the building´s compound energy concept the software Polysun Professional is used. In a first approach a basic concept was designed with the key parameters passive house standard, floor heating, fresh water modules with 45 °C, 120 m^2_{BF} south-oriented solar collectors with an angle of 30°, 10,000 l storage tank, a 22.2 kW heat pump and geothermal probes.

This concept, showing a solar thermal coverage for hot water of 76.4 % and for hot water and heating of 61.6 %, was then modified to analyse the influence of the parameters size of the collectors and the storage, type of the collector (flat plate collector, evacuated tube collector, PVT), regeneration of the geothermal probes, integration of the household appliances and the type of the back-up system (standard heat pump, gas heat pump, biomass boiler) to investigate the impact on the solar thermal coverage, the investment cost, but also the primary energy demand. In total 14 different variants were examined for the project location in this planning phase (see Table 2).

Table 2. Simulated variants (teamgmi).

Parameter	Unit	V1	V2	V3	V4	V5	V6	V7
Collector type		FPC	FPC	FPC	FPC	ETC	FPC	FPC
Collector size	m²	120	120	120	120	120	160	80
Storage size	l	10,000	7,500	5,000	10,000	10,000	10,000	10,000
HP capacity	kW	22.2	22.2	22.2	22.2	22.2	22.2	22.2
Gas-HP capacity	kW	-	-	-	-	-	-	-
Biomass boiler capacity	kW	-	-	-	-	-	-	-
Number of double-U probes 32mm/40mm		2	2	2	2	2	2	2
Length of probes	m	271	271	271	271	271	271	271
Regeneration of probes (Sept-Oct.)		Yes	yes	Yes	no	yes	yes	yes
Hot water demand	l/d	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Hot water temperature (withdrawal)	°C	45	45	45	45	45	45	45
Parameter	**Unit**	**V8**	**V9**	**V10**	**V11**	**V12**	**V13**	**V14**
Collector type		FPC	FPC	ETC	PVT	ETC	ETC	FPC
Collector size	m²	120	120	120	54	120	120	120
Storage size	l	10,000	10,000	10,000	4,000	10,000	10,000	10,000
HP capacity	kW	22.2	22.2	22.2	22.2	-	-	-
Gas-HP capacity	kW	-	-	-	-	-	-	41.6
Biomass boiler capacity	kW	-	-	-	-	25	25	-
Number of double-U probes 32mm/40mm		2	2	2	1	-	-	2
Length of probes	m	271	271	271	371	-	-	271
Regeneration of probes (Sept-Oct.)		Yes	yes	Yes	yes	-	-	yes
Hot water demand	l/d	1,570	1,570	1,570	1,000	1,000	1,000	1,000
Hot water temperature (withdrawal)	°C	45	60	60	45	45	45	45

In this first analysis most of the variants are showing a solar thermal coverage for hot water and heating of the building compound of approximately 60 % up to almost 70 % for V6 with an enlarged collector size of 160 m². But it has to be mentioned that the results are varying depending on the selected software template, especially those in which a biomass back-up is included. For a further comparison of the single parameters the same template should be used. Regarding the primary energy demand (non-renewable energy) the variants V12 and V13 with biomass, V14 with biogas heat pump and V11 with PVT are revealing the lowest values in the range between 17,500 and 21,000 kWh/a, followed by the variants with standard heat pumps, which are between 22,500 and 31,000 kWh/a, using primary energy factors of 0.5 for biogas [21] and 0.2 for wood as well as 2.6 for electricity [22]. In addition, in case of regeneration of the geothermal probes in September and October there is the possibility to use these for free-cooling in summer.

Summarizing the most important results, a qualitative comparison for 9 selected criteria on a 4-point scale from 0 (weak) to 3 (very good) for the simulated energy concepts is illustrated in Fig. 5, showing that all variants are relatively similar. Nonetheless V14, the variant with the gas heat pump, is showing the highest scoring, if powered with biogas, followed by the basic concept of V1.

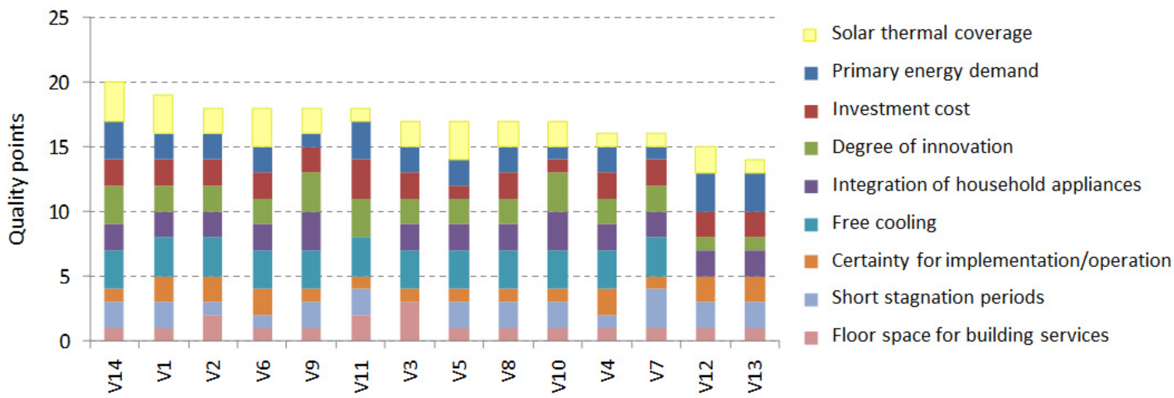

Fig. 5. (a) Qualitative rating of the simulated energy concepts (teamgmi).

5. Conclusion

The planning approach of the Life Cycle Habitation project shows promising findings towards the design of life-cycle oriented building concepts, which will be further developed in this ongoing integral planning process using conventional assessment tools like the Austrian energy certificate but also dynamic simulations programs like *energy plus* for detailed adjustment of all parameters. This includes the use of resource efficient building materials and constructions as well as an innovative and sustainable energy concept combined with an analysis of the ecological aspects to develop an overall concept for green buildings, which is suitable for further replication.

References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19. May 2010 on the Energy Performance of Buildings (Revised Version). Official journal of the European Union L 153/13.
[2] Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Recycling-Baustoffverordnung. Verordnung 181. Bundesgesetzblatt für die Republik Österreich. Österreich; 2015
[3] Lebensministerium. Bundes-Abfallwirtschaftsplan 2011, Umweltbericht im Rahmen der strategischen Umweltprüfung gem. RL2001/42/EG. Austria; 2011.
[4] Lebensministerium. Erläuterungen zur Recycling-Baustoffverordnung. BMLFUW-UW.2.1.6/0306-V/2/2015. Austria; 2016
[5] Reisinger K, Wimmer R, Burghardt M et al. *Studie Lewari – Vorprojektstudie zur Errichtung von Zero Carbon Village*. Österreichisches Programm für die Entwicklung des Ländlichen Raumes 2007-2013. Vienna. Austria: 2013
[6] Wimmer R, Eikemeier S, Burghardt M. *Zero Carbon Village - Energieautarke Siedlung, Industrielle Forschung*. Haus der Zukunft. Bundesministerium für Verkehr, Innovation und Technologie. Vienna. Austria; 2012
[7] Energieausweis-Vorlage-Gesetz; 2012 (https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2012_I_27/BGBLA_2012_I_27.pdf)
[8] Raft F, Frohn B. *Natürliche Klimatisierung*. Birkhäuser Verlag Basel. Switzerland; 2004
[9] IBO - Austrian Institute for Healthy and Ecological Building. Guideline for the calculation of ecological indicators for buildings. Version 3.0. Vienna. Austria; 2013
[10] ASBC - Austrian Sustainable Building Council. TQB Dokumentation Wohngebäude. Austria; 2014
[11] Krick B. *Untersuchung von Strohballen und Strohballenkonstruktionen hinsichtlich ihrer Anwendung für ein energiesparendes Bauen unter besonderer Berücksichtigung der lasttragenden Bauweise*. University Press Kassel, Germany; 2008
[12] ÖTZ - Österreichische Technische Zulassung/Austrian Technical Approval. OIB-no.: ÖTZ-2013/008/6. Product: S-HOUSE Ballen. Amt der Steiermärkischen Landesregierung, Department 15. Austria; 2013
[13] Wimmer R, Hohensinner H, Eikemeier S. et al. *Stroh-Cert: certification, logistic and quality management for straw bale buildings*. Haus der Zukunft. Bundesministerium für Verkehr, Innovation und Technologie. Vienna. Austria; 2011
[14] Bointner R, Bednar T, Eikemeier S. et al. *Gebäudeintegration - Gebäude maximaler Energieeffizienz mit integrierter erneuerbarer Energieerschließung*. Haus der Zukunft plus. Bundesministerium für Verkehr, Innovation und Technologie. Austria; 2012

[15] Wimmer R, Hohensinner H, Drack M, Kunze C. *S-House – Innovative Nutzung von nachwachsenden Rohstoffen am Beispiel eines Büro- und Ausstellungsgebäudes*. Berichte aus Energie- und Umweltforschung 2/2005. Bundesministerium für Verkehr, Innovation und Technologie. Vienna, Austria; 2005
[16] Eurostat.ec.europa.eu.. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production,_consumption_and_market_overview/de; 2013
[17] Schwarzer C. *Offenlegungsschrift DE 4142119 A1. Solarkocher*. Deutsches Patentamt. Bundesrepublik Deutschland. Germany; 1993
[18] Wimmer R. et al. *Zero Carbon Resorts Handbook Vol. 3*. European Union SWITCH-Asia program; 2014
[19] Wimmer R., Pokpong C., Eikemeier S et al. *Zero CO_2 Cooler – der Kühlschrank mit Warmwasseranschluss*. Neue Energien 2020. Klima- und Energiefonds. Austria; 2014
[20] Wegschneider-Pichler A.. *Strom und Gastagebuch 2008 – Strom- und Gaseinsatz sowie Energieeffizienz österreichischer Haushalte*. Projektbericht. Statistik Austria. Direktion Raumwirtschaft, Energie. Austria; 2009
[21] DIN V 18599-1: 2011-12. Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung - Teil 1: Allgemeine Bilanzierungsverfahren, Begriffe, Zonierung und Bewertung der Energieträger. Germany; 2011
[22] Passivhaus-Projektierungspaket PHPP. Passivhaus Institut, Germany; 2014