LIFE CYCLE HABITATION
ZERO CARBON BUILDING CONCEPTS

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ABSTRACT

Zero Carbon in the building industry is a goal that can be reached by focusing on energy- and resource-efficient solutions and by utilising renewable resources both for building materials and energy supply. By this, buildings and settlements can become CO_2 neutral and independent from fossil energy resources.

With the overall goal to demonstrate innovative building concepts, 6 residential units and 1 community centre ("Life Cycle Habitation") will be designed and built in Lower Austria to make energy-efficient settlements the standard of tomorrow.

INTRODUCTION

A relatively large percentage of energy and resource consumption occurs in the building sector (Directive 2010/31/EU). 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 energetic standards. Furthermore, energy for domestic hot water and appliances (like cooking stove, washing machine, light and other electrical devices) is required. Along the life cycle of buildings additional energy and resource consumption results from demolition and disposal of buildings or building parts at the end of their lifetime.

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 and 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 focused in Austria due to a massive increase of building waste in the last years. Although, according to the "Federal Waste Management Plan 2011" by the Ministry of Life (Lebensministerium, 2011), the total amount of waste decreased by 500.000 t to 53.543.000 t, waste from the building sector 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.

METHODS

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 is therefore based on energy-efficient building solutions (passive house components, improved household appliances, thermal insulation etc.) and on the utilisation of renewable resources for building materials to reach a lower energy demand for 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 a further reduction of the carbon footprint it is also necessary to have an energy system using locally available renewable resources.

To reach this goal, solutions in three strands will be implemented to reduce CO_2 emissions and waste of resources significantly over the entire life cycle:

1. Highly energy-efficient and sustainable building materials are used: straw bales are regional renewable resources with very low "grey energy" (100 times less than conventional insulation materials), they store CO_2 and provide high thermal insulation.
2. Innovative construction types (load-bearing and pre-fabricated modular constructions): Building components of the village will be produced in collaboration by local SMEs (Small and Medium Enterprises) that are organised in an efficient way.

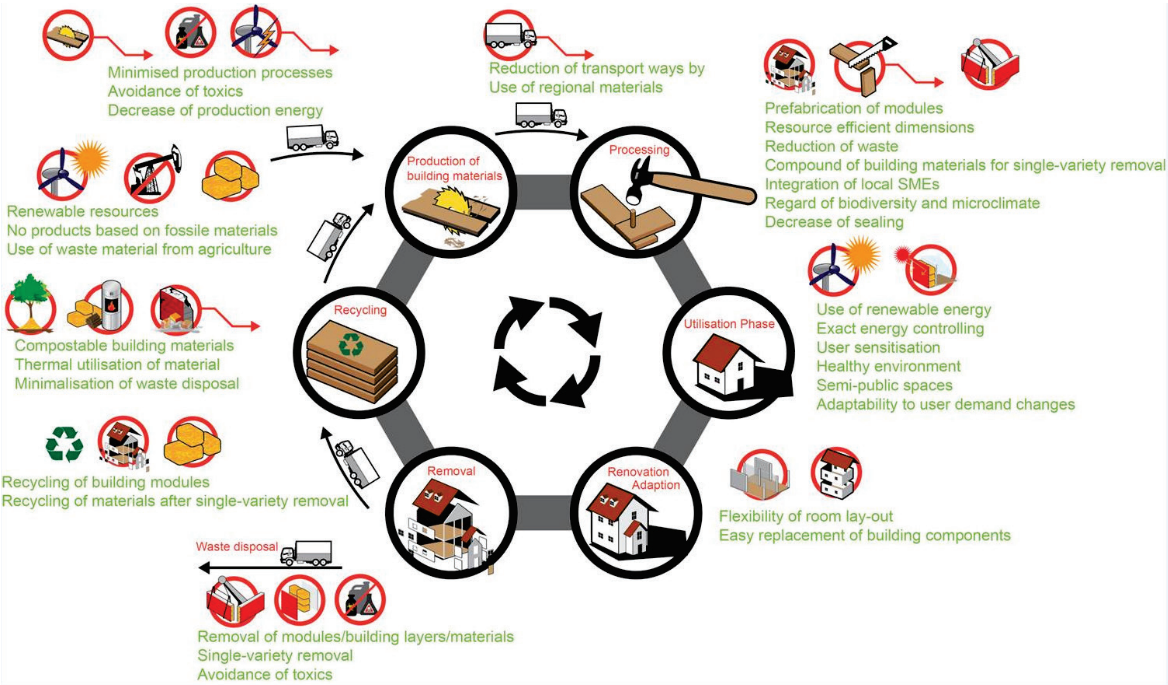


Figure 1 Project impact on the life cycle (own image)

3. Energy self-sufficiency: Renewable resources (solar energy, biomass) are used to generate thermal energy for thermal energy services and to generate additional electrical energy. (Wimmer et al., 2012)

SUSTAINABLE BUILDING MATERIALS

Assessments

Assessments and quality control of buildings can be executed on different levels and foci: Besides building rating programs such as LEED (USA) or WBS (Switzerland), the Austrian *klima:aktiv* assessment criteria show a broad approach including architectural quality, site, infrastructure, energy, social quality and economics (Klima:aktiv, 2012). A mandatory assessment instrument in Austria is the so-called *Energieausweis*, an indicator computing the energy demand per m^2 and year in accordance with national and European laws (EAGV, 2012).

Assessment of building materials is a sensitive topic: a big 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 (Raft et al., 2004). To improve environmental impacts these criteria are complemented in Life Cycle Habitation by two main strands:

1. Technical parameters (like heat conductivity, heat storage capacity, reaction to fire, vapour diffusion resistance, sound insulation or dimensional stability) are pre-conditions of material decisions for different elements of the building.

2. To minimise negative impact on the environment a low PEI (primary energy demand of non-renewable resources) in MJ/kg, GWP (Global Warming Potential) in kg CO_2/kg, and AP (Acidification Potential) in kg SO_2/kg, as shown by *Baubook*, is required (Baubook, 2014).

Renewable resources

Highly energy-efficient and sustainable building materials based on renewable resources, such as straw bales, have been proven to be functional, and show a very low PEI and positive effect for the CO_2 balance of the building (Krick, 2008). With the Austrian Technical Approval (ÖTZ) in 2010, the functionality of straw bales as an insulation material has been certified (Wimmer et al., 2011). Because of the simple production process (the raw material straw only needs to be pressed and tied up) the production energy of the straw bales is by a factor of 100 lower in comparison to conventional insulation materials such as EPS, comparing wall constructions with the same U-value (Figure 2).

But also 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 maufacturing process, materials made of renewable resources in contrary are able to store it (Figure 3).

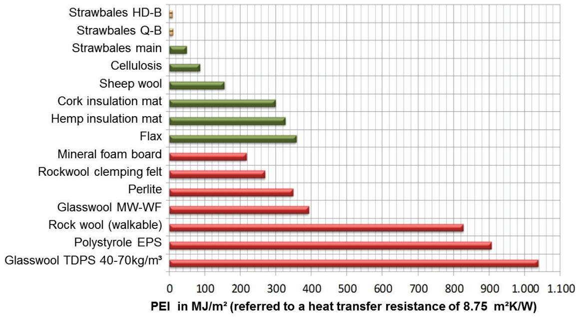


Figure 2 PEI of different insulation materials

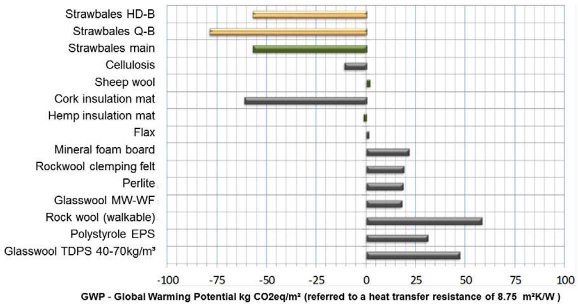


Figure 3 GWP of different insulation materials

Also, local availability is a core aspect for low grey energy of construction materials, considering the energy demand for transport. Through this, local economies, especially small and medium-sized enterprises, are stimulated by producing and using renewable materials and low carbon technologies for buildings and appliances. Materials and constructions with recycling or composting potential are preferred (Wimmer et al., 2012).

INNOVATIVE CONSTRUCTIONS

For a comparison it is important to evaluate the entire construction because not only individual construction materials can be re-used, recycled or used for energy production, but also whole building parts and modules. Figure 4 shows a comparison of a conventional wall element and a wall element constructed with renewable resources – mainly wood and straw bales – and their environmental and technical benchmarks. The best performance in respect to that criterion is shown by renewable resources such as straw bales, which can store CO_2 throughout the building's lifetime (Wimmer et al., 2011).

Modular prefabrication

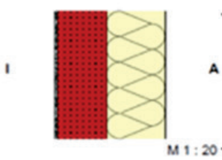
There are several variants for wall constructions using wood and straw for prefabricating single elements or entire constructions. Through the strategy of standardised prefabrication combined with an efficient coordination of the participating companies, waste will be reduced to a minimum as well as unnecessary material consumption through design and installation errors.

In industrial prefabrication, manufacturing processes of building components and modules are standardised so that the finished parts are aligned to each other. Therefore the construction time on the building site can be shortened, material waste reduced and assembly faults avoided.

Prefabrication is already possible for large elements, such as complete bathrooms units or rooms with integrated kitchens. Continuation of modularisation should encompass the manufacturing of compatible elements for the building envelope, housing technology as well as appliances. This requires inter alia a well-planned cabling concept for all components of the energy system (supply and demand side), which has to be developed already in the planning phase. The system of wires and pipes

AW brick-EPS

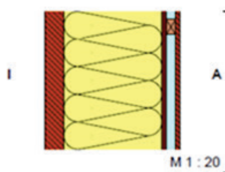
E-I



		d [m]	λ [W/mK]	R [m2K/W]	GWP [kgCO2eq/kg]	PEI n.e. [MJ/kg]	usage period
1	silicate plaster	0,0020	0,8	0,002	0,321	6,260	50
2	Polystirol EPS F	0,3000	0,040	7,500	3,490	102,000	50
3	brick	0,2500	0,415	0,602	0,176	2,390	100
4	cement plaster	0,0150	1,000	0,015	1,560	1,560	100
	heat transfer resistance			0,170			
					GWP	PEI n.e.	
		0,567	RT =	8,289	[kgCO2eq/m²]	[MJ/m²]	75
			U =	0,12	97,3216	1093,5	

AW straw-wood

E-I



		d [m]	λ [W/mK]	R [m2K/W]	GWP [kgCO2eq/kg]	PEI n.e. [MJ/kg]	usage period
1	wooden facade	0,0200			-1,690	2,270	60
2	wooden laths	0,0500			-1,600	4,290	60
3	clay plaster	0,0200	0,810	0,025	0,003	0,343	100
4	straw-bales	0,5000	0,045	11,111	-1,250	0,846	50
5	CLT-wood	0,1280	0,130	0,985	-0,080	4,600	100
	heat transfer resistance			0,170			
					GWP	PEI n.e.	
		0,7180	RT =	12,291	[kgCO2eq/m²]	[MJ/m²]	74
			U=	0,081	-96,49	390,16	

Figure 4 Comparison of two different wall constructions: conventional wall construction (above); construction with renewable and local materials (below)

should be kept short and without crossing so that the elements are easy and fast to connect on the construction site. The design of the floor plan types is important in this context as well if the modules and the housing technology are to be combined in an efficient way while still allowing flexibility.

Beside an efficient connection of the building envelope and housing technology in a high quality, modular building elements have the advantage of being easily assembled, disassembled and upgraded after their useful life or when user demands change within a *re-use system*.

Waste as well as time and energy can be saved during the building phase through prefabrication of elements and modules. This is not only beneficial for building owners, but also for manufacturers because of a more economic production with higher quality (Wimmer et al., 2009).

Construction types

A first variant of wall constructions consists of whole modules which have been prefabricated and filled with insulation material in the factory.

A second variant is to prefabricate individual elements, for instance wall modules containing small or big bales, and then let the involved SMEs of the cluster assemble them on the construction site.

For the second variant, as shown in Figure 4 (below), it is possible to prefabricate the elements made of CLT (cross laminated timber) accurately with a CNC shaper as well as the wooden components for the façade, which then are supplemented on site with the materials straw and clay, which were taken from 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 utilisation with decreasing added value (product and material recycling) and subsequent composting or energetic utilisation (thermal utilisation). 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 foreseen in the factory. Concerning re-use and recycling possibilities it is hence important to examine not only single 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 Figure 5 (Bointner et al., 2012).

These measures can of course also be adopted for variants of loadbearing or partially loadbearing systems – either single elements, which are used for the construction, or whole 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 (Wimmer et al., 2012).

ENERGY SELF-SUFFICIENCY

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 % (Eurostat.ec.europa.eu, 2013). This situation asks for a resource-efficient energy concept that foresees renewable energy sources, such as the one which is planned to be installed in the project Life Cycle Habitation.

In conventional energy systems in households, most appliances are operated by electricity although they

Wood-straw wall construction	Useful life	Composting	Product recycling	Material recycling	Thermal utilization	Disposal	Additives	Regional
CLT-wood	100	no	re-use	further use -> e.g. chipboards	yes - 18 MJ/kg	possible after thermal pre-treatment	very small proportion of binder materials (PUR adhesive)	yes
straw bales	50	yes (after opening)	re-use (if necessary cutting/tying -> insulation material)	further use (opening, if necessary baling) -> straw bales, fertilizer, bedding	yes - 17,5 MJ/kg	possible after thermal pre-treatment	thread (hemp, sisal, PP)	yes
clay plaster	100	yes (if only natural additives)	re-use (moistening with water, cleaning -> clay plaster)	further use (moistening with water) -> new clay products	not possible	disposal category 3 possible (but usually composting)	hemp, flax etc. possible	yes
wooden laths (timber, planed, tech. dried)	60	yes	re-use	further use -> e.g. chipboards	yes - 18 MJ/kg	possible after thermal pre-treatment	-	yes
wooden fasade (timber, rough, air dry)	60	yes	re-use	further use -> e.g. chipboards	yes -18 MJ/kg	possible after thermal pre-treatment	-	yes

Figure 5 Cascade of a wood-straw wall construction

actually provide thermal energy services. In contrast to this, energy self-sufficiency of the buildings in this demonstration settlement is based on the maximum utilisation of thermal energy gained from solar energy and biomass. All thermal appliances such as washing mashine, dishwasher or dryer are operated by thermal energy. Based on the idea of an indirect operated solar cooker (Schwarzer, 1993) a concept for an adopted and optimised version of this solar cooker was developed to be implemented in the community centre using thermal oil as a heat transfer medium in an additonal conduit system, while cooking for the living units is provided by biogas. The cooker is also equipped with a connection facility for a refrigerator and a freezer, which also require a higher temperature level for operation with thermal energy (Wimmer et al., forthcoming) (see also Figure 7).

Through a consequent consideration of the required form of energy and the use of the most appropiate technologies, it should be possible, based on the energy balance (input/output), to reduce the consumption of electrical energy by up to 80% compared to the median consumption of Austrian households as shown in Figure 6 (Wegschneider-Pichler, 2009).

Figure 6
Energy consumption and saving potential in Austrian households through LCH energy concept

electric loads in house-holds	median	electricity LCH	electricity reduction down to …	thermal energy LCH (excl. heating)
	kWh/a	kWh/a	%	kWh/a
hot water heating	1612	0	0	1612
recirculation pump	347	347	100	0
freezer	329	0	0	189
lighting	298	149	50	0
cooking devices	291	29	10	0
cooling devices	263	0	0	167
dishwasher	222	50	22	115
heating incl. operating energy	220	10*	5	6 kWh/m^{2}a**
dryer	178	50	28	264
washing machine	175	40	23	126
total	**3934 kWh/a**	**675 kWh/a**	**17 %**	**2473 kWh/a**

* ventilation system with heat recovery, not universally valid

** calculated energy demand for heating of the S-House (Wimmer et al., 2005)

It is foreseen that the size of the the project (6 residential units and 1 community centre) will be extendend after the project up to 80 units in different multi-storey buildings (two and three floors) as well as terraced houses with an average size of 85 m^2 for which the project results should be used as replication template. Electrical energy demand for the entire village is calculated to be about 54 MWh/a and thermal energy demand will be about 198 MWh/a (without heating). Because of measured solar radiation for the chosen location in Lower Austria (global radiation 1559 kWh/m^{2}a, direct radiation 710 kWh/m^{2}a, diffuse radiation 848 kWh/m^{2}a) (Meteonorm) a theoretical demand for 250 m^2 of photovoltaic panels as well as 767 m^2 of solar collectors has been calculated for the provision of all 80 living units. However, due to imbalanced radiation over the year, especially in winter, a biomass back-up system is necessary to cover the thermal energy demand, using e.g. logs or wood pellets. Technologies for the production of both thermal and electrical energy, such as micro-CHP, are an optimal supplement for solar collectors and photovoltaic systems in winter seasons. For provision of the cooking devices 28 m^3/d of biogas are needed, which can be produced in a local biogas plant close by (Reisinger et al., 2013).

DISCUSSION AND CONCLUSION

To reach the overall objective of this project, the demonstration of innovative building concepts that significantly reduce CO_2 emissions and contain a minimum of grey energy (i.e. energy from fossil fuels) over their entire lifecycle and to make energy-efficient settlements the standard, in line with EU 2020 objectives, it is necessary to combine the three strands: sustainable building materials, innovative constructions, and energy self-sufficiency, each of which shows great effects for reducing primary energy demand. For implementation and further replication on a larger scale, 3 building types (apartment, townhouse and compacted flat-roof buildings with an effective area of approximately 710 m²) will be combined. Urban development aspects will also be taken into account, since building compounds bring in additional resource-saving options as compared to individual buildings: Building density, number of stories, A/V (surface area/volume) ratio and building orientation are factors that influence heating energy demand and which are relevant for integration into the urban environment. High density housing thus shows advantages compared to one-family houses (Bußwald et al., 2011).

The emphasis on material and energy decisions is seen in a broader scope of different requirements: The dense typologies are complemented by services to target an efficient overall concept, such as collective waste management or mobility concepts (support of public transportation, car sharing programs, charging stations for e-cars, individual parking places exclusively situated at the boundary of the area). The outdoor area can be designed using environmentally materials for pathways

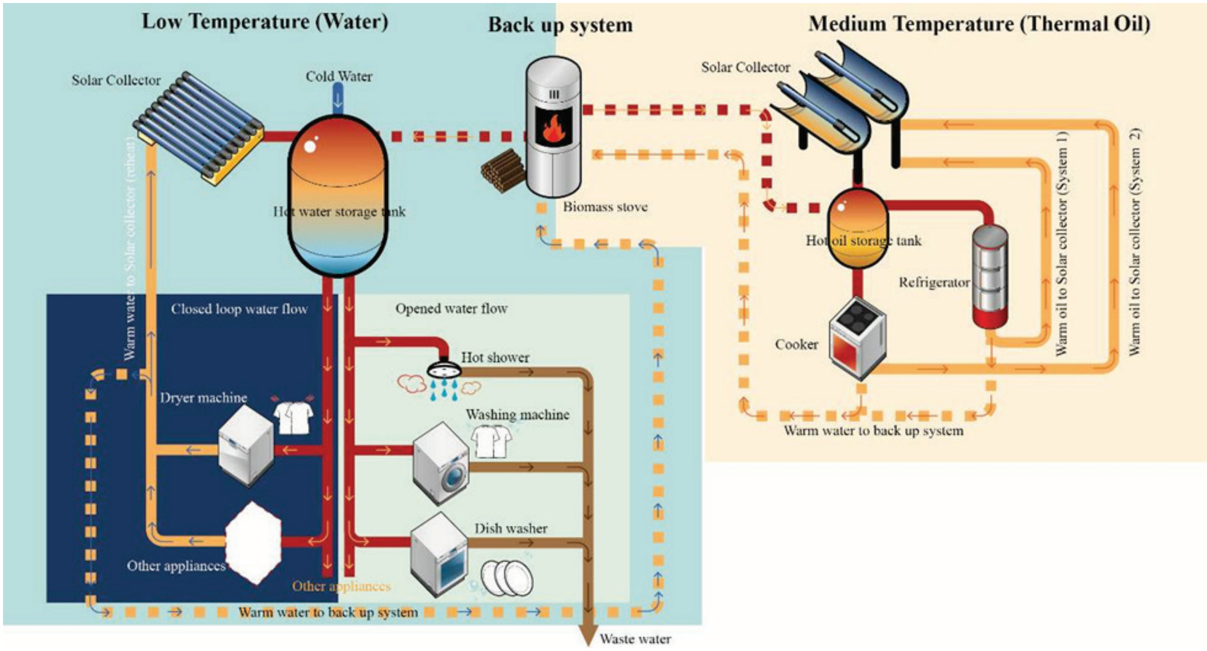


Figure 7 Thermal-based energy system for Life Cycle Habitation (own image)

(Hohensinner et al., 2011) and green areas as well as common kitchen gardens can be provided.

In order to reach sustainable development of the settlement, it is necessary to provide different options for housing and usage so as to attract diverse demographic target groups (varying in age, income, family status, etc.).

Taking into account these planning aspects on a larger scale and combining them with energy and resource-efficient solutions on a technical level thus brings about carbon neutral solutions which can also be up-scaled to urban development.

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