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Development of modular wooden buildings with focus on the Indoor Environmental Quality

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ABSTRACT: During the last three decades there has been increasing concern within the scientific community about the effects of indoor air quality on health. Changes in building design devised to improve energy efficiency and has induced that modern homes and offices are frequently more airtight than older structures. Furthermore advances in construction technology have caused an extensive use of synthetic building materials. The construction process and the production of building materials not only consume the most energy they also have a big impact on the Global Warming Potential. While these improvements have led to more comfortable buildings with lower running costs, they also provide indoor environments in which contaminants are readily produced and may build up to much higher concentrations than outside. Because about 80-90% of our time is spent indoors, where we are exposed to chemical and biological contaminants and possibly carcinogens, the Indoor Environmental Quality plays an increasing role. The aim of this study was to develop building components out of sustainable natural materials for modular building concepts with regard to the Indoor Environmental Quality such as the air quality and the indoor climate, the temperature and humidity. To guarantee high Indoor Air Quality a mechanical ventilation system is part of the construction. It has to ensure a controlled air change with a minimum of dissipation of energy. Building parts were assembled to meet high energy efficiency Standards. For the construction parts wood, hemp, sheep wool and clay were used to meet the settled requirements. As a first result of this study two modular buildings were erected, in which the indoor air quality and the construction physics will be monitored in the next few years for generating valuable data.

KEYWORDS: natural materials, wood, VOC, formaldehyde, living health, construction physics, Indoor Environmental Quality, air quality

1 INTRODUCTION

Buildings in EU consume on average about 40% of all produced energy and produce approximately 30% of CO_2 emission and 40% of total waste [1]. The problem of sustainability of buildings is very complex and includes a large number of parameters and criterions from different areas of technical as well as non-technical sciences. Common used parameters which reflect the environmental impact of building components are the three main materials related characteristics: Potential of Energy Intensity (PEI), Global Warming Potential (GWP) and the Acidification Potential (AP).

Furthermore there is growing public awareness regarding the risk associated with poor indoor air quality in the home and workplace. People in modern societies spend about 90% of their time indoors [2]. Hence, indoor environmental quality (IEQ) has a significant impact on public health and well-being [3]. Not only the feeling of subjects in rooms with increasing ventilation-rate is generally better but also benefits in productivity were shown in past studies [4]. In modern buildings it is unalterable to install ventilation devices for supplying fresh air. To create a good and comfortable indoor climate and to ensure a low-emission housing environment is related to hygienic factors and eco-political important. Unlike for the ambient air and workplaces in the private interior space there is to date no regulation for indoor air quality or generally binding regulatory laws for emission limits. Only some guidelines exist e.g. AGBB scheme in Germany [5]. In Germany, new building products must meet requirements intended to limit potential adverse health and safety effects, or objectionable nuisance for occupants. These are national building code regulations administered by the German Institute for Building Technology (DIBt). Some special requirements apply to selected building products used indoors. In particular, floor coverings must be tested for their emissions of volatile organic compounds (VOCs) and must meet the requirements of an evaluation scheme administered by the German Committee for Health-Related Evaluation of Building Products (AgBB). This AgBB scheme is titled “Health-related Evaluation Procedure for Volatile Organic Compounds Emissions (VOC and SVOC) from Building

Products”. There is now an increasing emphasis on the selection of low emitting materials at the design stage of a building in order to avoid indoor air pollution problems. Therefore the best way to control and reduce indoor air pollution of VOC´s emitted from building materials is “source control” by evaluation and proper material selection [7].
Another way is to reduce the present substances in indoor air to a healthy and hygienic level. This should be made by ventilation devices and is necessary in order to extract the exhausted air. Mechanical ventilation systems offer also the advantage of keeping the thermal losses very low in comparison to window-ventilation.

The construction industry is based on craftsmanship. Quality control and assurance procedures applied in manufacturing cannot usually be readily applied in construction, as there are high degrees of uniqueness in each project. By prefabricating building modules for later assembly at the building site the control and improve of the quality in a more consistent way than in ordinary constructions is possible [8].
Modular buildings show following key advantages compared to conventional buildings, including:

- shorter construction time
- reduced site disruption
- consistent quality
- financial savings [9].

The aim of this study was to develop building components out of sustainable natural resources with low PEI and GWP for modular building concepts with regard to the Indoor Environmental Quality such as the air quality and the indoor climate, the temperature and the humidity. The building parts were assembled to meet high energy efficiency Standards in Austria with focus on the use of natural sustainable materials. For the construction parts wood, hemp, sheep wool and clay were used to meet the settled requirements. The first result were two realised prototype buildings in which the indoor air quality and the physical parameters are monitored since March 2013 to autumn 2014 generating valuable data for future buildings.

2 Energy Efficient HVACR Systems

In the past most module buildings like containers were built with low energetic quality of the thermal envelope. During the period of use different lacks of comfort occur inside of such buildings [12]. In order to maintain the operation energy-intensive heating-, ventilation-, aircondition- and refridging- (HVACR) systems have to be retrofitted.
In the present project a different and more sustainable way was selected. The building envelope meets the Passivhaus-criterias (PH-Quality) for reaching a high level of IEQ from the very first day. A critical choice of materials was made for several reasons. Important was to save primary energy input (see 4 METHODS) but also to save the maintaining input of energy by using the right material in the right place.
Energy-efficient building envelopes are in any case very airtight. One value to determine the airtightness of a building is the n_{50} value which defines the air change rate at a constant pressure graduate of 50 Pascal between indoor and outdoor [13]. This Value was set at n_{50} = 0.6 1/h for PH-Quality. To extract the exhausted air and for supplying fresh air a mechanical ventilation system has to be installed. The system which is applied in the project is equipped with a highly efficient heat recovery and needs only little energy for the fans.

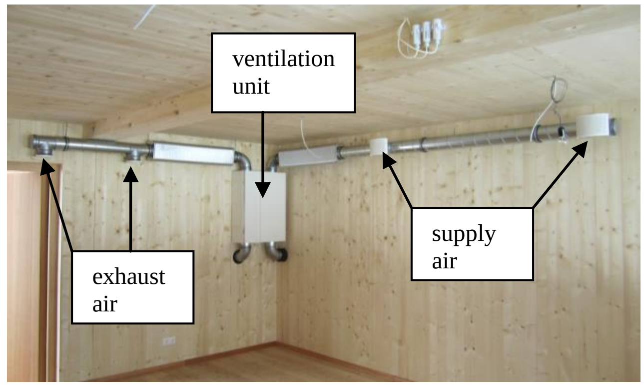


Figure 1: *built in mechanical ventilation system in the wooden module*

The mechanical ventilation can be controlled manually or automatically. In order to guarantee high IAQ the ventilation is controlled by the CO_2 concentration inside the room. The measured CO_2 concentration is a product of human metabolism and indicates organic emissions in general [6].
While past studies in buildings without mechanical ventilation show high rates of low IAQ, ventilation systems can improve the Quality of Indoor Air regarding to the CO_2 value significantly [10].

Table 1: *Classification of IAQ regarding to* [11]

IAQ	CO_2 – concentration above outdoor (dCO_2)
special	≤ 400 ppm
high	401 – 600 ppm
medium	601 – 1000 ppm
low	1001 – 1500 ppm
very low	> 1500 ppm

3 MATERIALS

One of the goals in this project was to develop natural and environmental friendly components for modular buildings. Therefore the technical data of the materials were the most important point for the selection as the building physical requirements have to be fulfilled.

After a product search following materials were chosen:

- timber frame construction in one case and cross laminated timber (CLT) made of Norway spruce for structural elements in the second case
- clay as an humidity balancing material (inside the room) for the wood frame construction
- sheep wool was selected as thermal insulation material and for absorbing air pollutions.
- hemp wool was selected for the outer thermal insulation
- for the cladding wood planks and wood shingles were chosen
- the roof was covered with a flexible Polyolefine FPO- roofing system

Wood, a material that requires a minimal amount of energy-based processing, has a low level of embodied energy relative to many other materials used in construction (such as steel, concrete, aluminum, or plastic). Solid sawn wood products have the lowest level of embodied energy; wood products requiring more processing steps (for example, plywood, engineered wood products, flake-based products) require more energy to produce but still require significantly less energy than their non-wood counterparts [14]. Due to its low thermal conductivity (ca. 0.12-0.15 W/m²K) thermal bridges within the construction in wood constructions are reduced in comparison to other materials.

Cross laminated timber (CLT) is an engineered wood building system designed to complement light- and heavy-timber framing options. Because of its high strength and dimensional stability, it can be used as alternative to concrete, masonry and steel in many building types. CLT is manufactured using softwood from sustainably managed forests. In comparison to other solid construction methods, the manufacture and processing of cross laminated timber elements requires less energy, assists in permanent CO_2 storage and minimises the greenhouse effect [15]. Well-insulated building component structures with visible timber surfaces result in surface temperatures close to the room air temperature, which is a considerable contribution to an increase in comfort. At the same time, the high size proportion and the level of specific moisture and heat accumulation capacity of the softwoods used also assist in regulating the residential climate. It therefore plays its part in a healthy room climate.

Like no other building material, earth and clay fulfil today's ecological and economic requirements. It is locally available, requires few other resources, can be recycled, is easy and agreeable to work with, has good insulating properties and is free of emissions. Its use in buildings improves the internal room climate significantly. Through the absorption and release of moisture it regulates the relative air humidity naturally and maintains comfortable surface temperatures. Furthermore, clay and earth have good insulating properties and can offer excellent sound insulation.

Being made from a naturally produced fibre, Sheep Wool Insulation requires less than 15% of the energy required to produce than glass fibre insulation. It can absorb and break down indoor air pollutants, such as formaldehyde, nitrogen dioxide and sulphur dioxide. Investigations on sheep wool show, that it absorbs and chemically binds formaldehyde (H_2CO) within the wool fibres [16]. Wool is a sustainable and renewable resource, that has zero ozone depletion potential and at the end of its useful life it can be remanufactured or biodegraded.

Timber cladding e.g. wood planks and wood shingles offers designers a unique combination of practical, aesthetic and environmental advantages as wood products in general. Additionally timber cladding panels may be factory pre-fabricated including insulation and breather membrane.

Flexible Polyolefine (FPO) roofing sytems have a limited environmental impact compared to other roofing membranes, both during the manufacture and installation process. The polyolefins include the plastics polyethylene and polypropylene used in mass production. Since polyolefins are thermoplastics and can be repeatedly melted, they are an easily recyclable raw material. The used Sarnafil® TS 77 roofing system is a Polyester reinforced, multi-layer, synthetic roof waterproofing sheet based on premium-quality flexible polyolefins containing ultraviolet light stabilizers, flame retardant and an inlay of glass non-woven [17].

4 METHODS

For optimizing the wall and the floor slabs the calculations were made by using the online data base "baubook" [18]. Within this database a wide range of materials can be selected and most relevant technical data related to building aspects are implemented in the database. The outcomes of the selected material combinations are following parameters:

- the overall element thickness
- the mass of one m² of an element kg/m²
- the heat transfer coefficient U-value (formerly k-value) W/m²K
- Primary Energy Intensity (PEI) MJ/m²
- Global Warming Potential (GWP) CO_2/m²
- Acidification Potential (AP) SO_2/m²
- data on the overall environmental impact of the element the OI3 indicator, which combines the GWP CO_2/m² emission, the AP SO_2/m² emissions and the PEI MJ/m².

The **U-value**, calculated according to ÖNORM EN ISO 6946 [19], is the most important value for high energy efficient buildings. This value indicates the rate of heat transfer through a specific component over a given area if the temperature difference is exactly one degree (1 Kelvin). The measurement unit of the U-value is therefore “W/(m²K)”.

PEI expresses the material’s embodied energy. It is quoted frequently in MJ per mass of material or per square meter of evaluated construction.

GWP establishes the relative climate effects of greenhouse gases relating to the building material production. Carbon dioxide, the most important greenhouse gas, is used as a reference parameter with a set GWP value of 1. An equivalent amount of carbon dioxide in kilograms is calculated for every greenhouse-effective substance with this value depending on the gas heat absorption properties and the persistence of the gas in the atmosphere.

A**P** conveys the tendency of the material to contribute to the acidification processes. Acidification is mainly caused by the interaction of nitrogen oxide (NOx) and sulfur oxide (SO_2) with the air components. Acidification is measured in sulfur dioxide equivalents and an equivalent amount of sulfur dioxide in kilograms is calculated for every acid-effective substance [20].

The **OI3** index combines the PEI, the GWP emission, and the AP emissions. For the calculation of a single layer see for example Equation below:

$$\Delta OI3_{BS} = \frac{1}{3} \cdot \left[\frac{1}{10} \cdot \left(PEIne\right)_{BS} + \frac{1}{2} (GWP)_{BS} + \frac{100}{0,25} (AP)_{BS} \right]$$

… where PEIne = Primary Energy Intensity not renewable in MJ/m², GWP = Global Warming Potential in kg CO_2 equivalent/m² , AP = Acidification Potential SO_2 equivalent/m². The index BS stands for single construction elements. The $\Delta OI3_{BS}$ indicator supports a quick optimization of single layers because ecological significance can be determined very simple the higher the indicator the more impact the product has on the environment.

The $OI3_{KON}$ indicator for the whole construction is not as expected the sum of the single layers $\Delta OI3_{BS}$, it is reduced by 109/3 due to the calculation method for the thermal building envelope (= Thermische Gebäude Hülle (TGH)) in Austria. Therefore the OI3 index can reach from -30 to 120. Negative values are only possible with high ecologically optimized constructions, but those are settled to zero in the Austrian rating system. Usual ecologically not optimized constructions are in the range of 70 and optimized constructions or lightweight constructions are in the range of 15 [21].

For determining the humidity and temperature profile inside the construction data sensors were placed at different depth, which log the humidity and temperature in the construction and inside the modules. s. Figure 2. This should give information on the usability of the tested materials. The air quality will be regularly monitored by taking air samples in using DNPH-cartridges for the formaldehyde concentration and TENAX TA ®- tubes for determining the VOC components. The chemical analysis is made by using HPLC and GC in a chemical laboratory. Additionally sensors inside the Room log the temperature, the humidity and the CO_2 amount which gives Information on the air quality resp. the oxygen consumption of the user. As for these analyses long term investigations are necessary, valuable results will be presented at a later step.

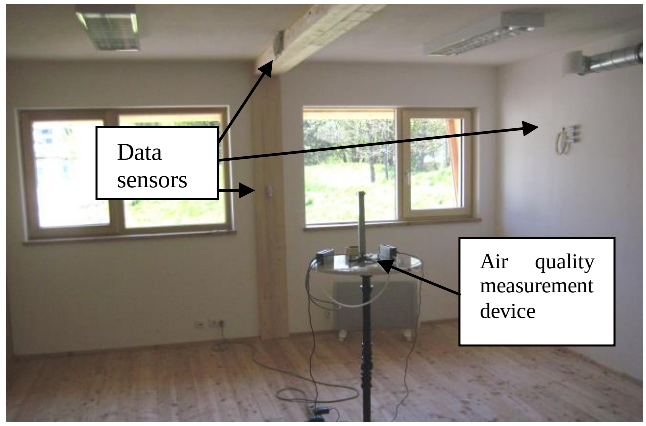


Figure 2: *Realized wooden building module inside of the framing and clay module during air quality measurements*

5 RESULTS AND DISCUSSION

Two realized buildings, each is made of two single modules, with the dimension of about 5.5 m in width, 6 m in length and 3 m in the height were built as modular constructions s. Figure 3. The single modules allow a fast and easy assembly on site. Within two days the CLT-module was ready for use. For the module with clay inside, the finishing layer was applied on the wall after mounting the modules for avoiding cracks due to transportation.

The building elements were dimensioned to meet high energy efficiency standards (eg. U-Value ca. 0.15 – 0.18 W/m²K) and ecological aspects s. Figure 4 to Figure 9 and fulfilling high standards regarding the indoor air quality.

The PEI for the elements has a range from 405 to 951 MJ/m².

Out of the dataset it can be realized that the GWP for all Building parts is negative in between 56 – 93 kg CO_2/m². That means more CO_2 is bonded within the construction than emitted due to the production.

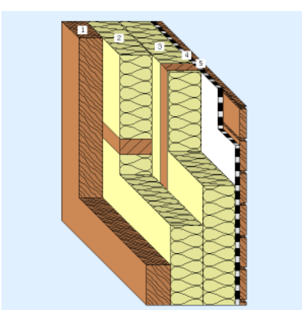
The $\Delta OI3_{BS}$ indicator shows that the timber construction parts are in a very low range in comparison to concrete or brick constructions. None of the elements reaches the $\Delta OI3_{BS}$ indicator of 46, which would be calculated for 20 cm concrete structure without any other layer. CLT with 22 points has the largest $\Delta OI3_{BS}$ indicator within the different construction elements. Due to the calculation method the $OI3_{KON}$ indicator for the whole construction only reaches positive values for the CLT wall and roof element. All other elements are negative between

-0.3 to -21.4. This shows that the material selection is highly optimized regarding ecological aspects.

Table 2: *Overview on the PEI, GWP, AP and the OI3$_{KON}$ indicator of the construction elements*

Construction	*primery energy nonrenewable* PEI MJ/m²	global warming potential GWP kg CO_2eq/m²	acidification AP kg SO_2eq/m²	*environmental indicator for the whole construction* OI3$_{KON}$
CLT wall element	756,6	-77,96	0,199	2,7
CLT roof element	950,5	-89,46	0,225	10,7
CLT floor element	748,1	-93,15	0,202	-0,3
Timber frame wall element	558,0	-55,65	0,123	-10,3
Timber frame roof element	682,7	-63,38	0,130	-7,3
Timber frame floor element	404,7	-65,47	0,093	-21,3

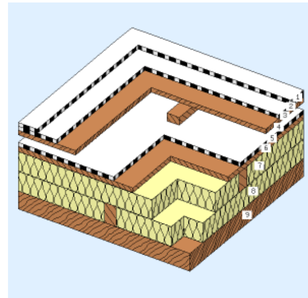
Figure 3: *Realized wooden building modules from the outside (left: CLT-construction, right: wood frame and clay construction)*



u - value	0,171 W/m²K
mass	74,8 kg/m²
PEI n. e.	756,55 MJ/m²
GWP100	-77,9564 kg CO_2/m²
AP	0,199106 kg SO_2/m²

no.	*CLT wall element* layer	*size* d cm	*thermal conductivity* λ W/mK	*thermal resistance* R m²K/W	*environmental indicator* ΔOI3 Pkt/m²
1	CLT - cross laminated timber	9	0,12	0,75	22
2	90 % hemp insulation (Thermo-Hanf)	12	0,045	2,667	7
	10 % spruce timber (batten)	12	0,12	1	0
3	90 % hemp insulation (Thermo-Hanf)	12	0,045	2,667	7
	10 % spruce timber (counter-batten)	12	0,12	1	0
4	open membrane (pro clima Solitex WA)	0,045	0,22	0,002	1
5	larch timber (planed joint shuttering)	2,4	0,13	0,185	1
	R_{si} / R_{se} =		0,130 / 0,040		
	R' / R'' (max. relative deviation: 2,7%)		6,014 / 5,702		
Σ	**module**	**35,45**		**5,858**	**39**

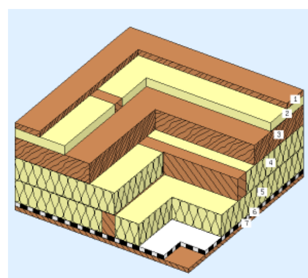
Figure 4: *Detailed data of the CLT wall element*



u - value	0,183 W/m²K
mass	87,9 kg/m²
PEI n. e.	950,50 MJ/m²
GWP100	-89,4646 kg CO2/m²
AP	0,225165 kg SO_2/m²

Nr.	*CLT roof element* layer	*size* d cm	*thermal conductivity* λ W/mK	*thermal resistance* R m²K/W	*environmental indicator* ΔOI3 Pkt/m²
1	TPO lining (Sarnafil TS 77)	0,18	0,17	0,011	7
2	non-woven material	0,1	0,1	0,01	3
3	spruce timer (planed shuttering)	2,3	0,12	0,192	1
4	91% air layer	4	0,25	0,16	0
	9 % spruce timber (batten)	4	0,12	0,333	0
5	membrane (Diffu light compact)	0,08	0,22	0,004	2
6	spruce timer (shuttering)	2,5	0,12	0,208	-1
7	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (counter-batten)	10	0,12	0,833	0
8	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (batten)	10	0,12	0,833	0
9	CLT - cross laminated timber	9	0,12	0,75	22
	R_{si} / R_{se} =		0,100 / 0,040		
	R' / R'' (max. relative deviation: 2,6%)		5,591 / 5,312		
Σ	**module**	**38,16**		**5,451**	**47**

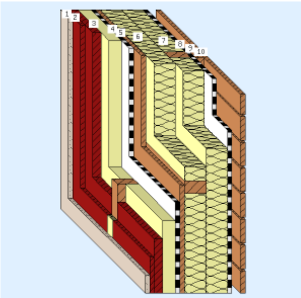
Figure 5: *Detailed data of the CLT roof element*



u - value	0,161 W/m²K
mass	84,8 kg/m²
PEI n. e.	748,06 MJ/m²
GWP100	-93,1458 kg CO_2/m²
AP	0,202191 kg SO_2/m²

Nr.	*CLT floor element* layer	*size* d cm	*thermal conductivity* λ W/mK	*thermal resistance* R m²K/W	*environmental indicator* ΔOI3 Pkt/m²
1	larch timber floor	2,5	0,13	0,192	1
2	92 % sheep wool insulation	4	0,046	0,87	1
	8 % spruce timber (batten)	4	0,12	0,333	0
3	CLT - cross laminated timber	9	0,12	0,75	22
4	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (batten)	10	0,12	0,833	0
5	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (counter-batten)	10	0,12	0,833	0
6	open membrane (pro clima Solitex WA)	0,045	0,22	0,002	1
7	spruce timber (shuttering)	2	0,12	0,167	-1
	R_{si} / R_{se} =		0,170 / 0,170		
	R' / R'' (max. relative deviation: 2,5%)		6,362 / 6,053		
Σ	**module**	**37,55**		**6,207**	**36**

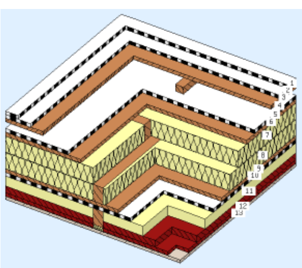
Figure 6: *Detailed data of the CLT floor element*



u - value	0,161 W/m²K
mass	115,4 kg/m²
PEI n. e.	558,00 MJ/m²
GWP100	-55,6521 kg CO_2/m²
AP	0,123180 kg SO_2/m²

Timber frame - clay wall element		*size*	*thermal conductivity*	*thermal resistance*	*environmental indicator*
no.	**layer**	**d** **cm**	**λ** **W/mK**	**R** **m²K/W**	**ΔOI3** **Pkt/m²**
1	loam rendering	1	0,81	0,012	0
2	90 % clay (800 - 1200 kg/m3)	0,8	0,3	0,027	2
	10 % wood fiberboard	0,8	0,05	0,16	0
3	36 % clay (800 - 1200 kg/m3)	4	0,3	0,133	8
	54 % sheep wool insulation	6	0,04	1,5	2
	10 % spruce timber (frame type column)	10	0,12	0,833	0
4	open membrane (pro clima Intello plus)	0,02	0,22	0,001	1
5	spruce timber (shuttering)	2,2	0,12	0,183	-1
6	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (batten)	10	0,12	0,833	0
7	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (counter batten)	10	0,12	0,833	0
8	open membrane (pro clima Solitex WA)	0,045	0,22	0,002	1
9	90 % air layer	4	0,222	0,18	0
	10 % spruce timber (batten)	4	0,12	0,333	0
10	larch shingles	2,2	0,12	0,183	1
	R_{si} / R_{se} =		0,130 / 0,040		
	R' / R'' (max. relative deviation: 3,5%)		6,415 / 5,986		
Σ	**module**	**40,27**		**6,201**	**26**

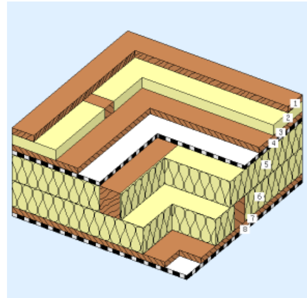
Figure 7: *Detailed data of the Timber frame wall element for the wood framing and clay construction*



u - value	0,153 W/m²K
mass	96,3 kg/m²
PEI n. e.	682,74 MJ/m²
GWP100	-63,3779 kg CO_2/m²
AP	0,130461 kg SO_2/m²

Timber frame - clay roof element		*size*	*thermal conductivity*	*thermal resistance*	*environmental indicator*
no.	**layer**	**d** **cm**	**λ** **W/mK**	**R** **m²K/W**	**ΔOI3** **Pkt/m²**
1	TPO lining (Sarnafil TS 77)	0,18	0,17	0,011	7
2	non-woven material	0,1	0,1	0,01	3
3	spruce timer (planed shuttering)	2,3	0,12	0,192	1
4	92% air layer	4	0,222	0,18	0
	8 % spruce timber (batten)	4	0,12	0,333	0
5	membrane (Sarnafil TU 222)	0,08	0,22	0,004	2
6	spruce timber (shuttering)	2,4	0,12	0,2	-1
7	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (batten)	10	0,12	0,833	0
8	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (batten)	10	0,12	0,833	0
9	spruce timber (shuttering)	2,2	0,12	0,183	-1
10	open membrane (pro clima Intello plus)	0,02	0,22	0,001	1
11	54 % sheep whool insulation	6	0,04	1,5	2
	36 % clay (800 - 1200 kg/m3)	4	0,14	0,286	3
	spruce timber (beam)	10	0,12	0,833	0
12	90% clay (800 - 1200 kg/m3)	0,08	0,14	0,006	0
	10 % wood fiberboard	0,08	0,05	0,016	0
13	loam rendering	1	0,81	0,012	0
	R_{si} / R_{se} =		0,100 / 0,040		
	R' / R'' (max. relative deviation: 2,9%)		6,708 / 6,325		
Σ	**module**	**42,36**		**6,517**	**29**

Figure 8: *Detailed data of the Timber frame roof element for the wood framing and clay construction*



u - value	0,179 W/m²K
mass	54,4 kg/m²
PEI n. e.	404,73 MJ/m²
GWP100	-65,4713 kg CO_2/m²
AP	0,093382 kg SO_2/m²

Timber frame - clay floor element		*size*	*thermal conductivity*	*thermal resistance*	*environmental indicator*
no.	**layer**	**d** **cm**	**λ** **W/mK**	**R** **m²K/W**	**ΔOI3** **Pkt/m²**
1	larch timber floor	2,5	0,13	0,192	1
2	92 % sheep whool insulation	4	0,046	0,87	1
	8 % spruce timber (level pole)	4	0,12	0,333	0
3	spruce timber (shuttering)	2,2	0,12	0,183	-1
4	open membrane (pro clima Intello plus)	0,02	0,22	0,001	1
5	87 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	13 % gluelam timber	10	0,12	0,833	2
6	90 % hemp insulation (Thermo-Hanf)	10	0,045	2,222	6
	10 % spruce timber (level pole)	10	0,12	0,833	0
7	spruce timber (shuttering)	2,2	0,12	0,183	-1
8	open membrane (pro clima Solitex WA)	0,045	0,22	0,002	1
	R_{si} / R_{se} =		0,170 / 0,170		
	R' / R'' (max. relative deviation: 2,9%)		5,745 / 5,420		
Σ	**module**	**30,97**		**5,582**	**15**

Figure 9: *Detailed data of the Timber frame floor element for the wood framing and clay construction*

Ongoing Investigations

The Indoor Environmental Quality will be monitored during a period of two years. The monitoring will be made during the use as an office and each building will be used by two persons. Especially the humidity balancing effect of the used materials (wood and clay) and the energy consumption will be part of the continuous monitoring.

Results of this monitoring will be presented at a later step as the buildings were erected in March 2013 and the use as office started in October 2013. Therefore at the moment limited data are available.

First results show the expected high decrease of TVOC after the first six month which was determined by a reduction of about 60-90% in comparison to the measurement at day 28 as reference according to the Standard ISO 16000-3 for VOC´s [22] and a reduction of about 42-46% according to ISO 16000-6 for formaldehyde [23].

6 CONCLUSION

Evaluation of the impacts, not only building materials but the construction at all, has the importance of maintaining both environmental quality and human health.

The realized modular wooden buildings show that with regard to environmental issues it is possible to build up in high energy standards by using natural sustainable and environmental friendly building materials such as CLT, clay, sheep wool and hemp. Energy-efficient mechanical ventilation systems supply fresh air and support the high level of Indoor Environmental Quality.

The investigations concerning the IEQ such as the determination of TVOCs and Formaldehyde are in action, but first results after six month show a high declination of the values and first toxicological assessment of the evaluation shows potential for low emission and high environmental quality of the chosen materials. More details and analysis will be given in a later step because the data collections are ongoing until winter 2014.

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REFERENCES

[1] Hájek P. amd Vonka M.: ENVIRONMENTAL ANALYSIS OF RESIDENTIAL BUILDINGS- LIFE CYCLE ASSESSMENT, SB04 Warsaw: Regional Central and Eastern Conference on Sustainable Building, 2004

[2] Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S., Raizenne M.E.: It'sabout time: a comparison of Canadian and American time-activity patterns. J. Expo. Anal. Environ. Epidemiol. 12, 427–432, 2002

[3] Wu F., Jacobs E., Mithcell C., Miller D., Karol M.h.: Improving Indoor Environmental Quality for Public Health: Impediments and Policy Recommendations, Envirnmental Health Perspectives, Vol. 115, No. 6 pages 953-964, 2007

[4] P. Wargocki, D. P. Wyon, J. Sundell, G. Clausen und P. O. Fanger, „The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptomes and Productivity,“ *Indoor Air,* pp. 222-236, 10 2000.

[5] AgBB (Ausschuss zur gesundheitlichen Bewertung von Bauprodukten): AgBB - Bewertungsschema für VOC aus Bauprodukten, Jun 2012

[6] Richtlinie zur Bewertung der Innenraumluft: Physikalische Faktoren: Kohlenstoffdioxid als Lüftungsparameter, BMLFUW, Wien 2011

[7] Wolkoff P. and Nielsen P.A.: A NEW APPROACH FOR INDOOR CLIMATE LABELLING OF BUILDING MATERIALS-EMISSION TESTING, MODELLING AND COMFORT EVALUATION, Atmospheric Environment Vol. 30, No. 15, pp2689-2679, 1996

[8] Johnsson H. and Meiling H.: Defects in offsite construction: timber module prefabrication, Construction Management and Economics, Vol. 27:7, pages 667-681, 2009

[9] Rogan A. L., Lawson R.M., Bates-Brekljac N.: Value and Benefits Assessment of Modular Construction, The steel and construction institute, UK, 200

[10] IBO project 2020, Akzeptanzverbesserung energieeffizienter Häuser durch Erhebung der Raumluftqualität und der Auswirkung auf die Gesundheit der Bewohner

[11] EN 13779:2004, Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems

[12] H.-P. Rammer, „Wohnhygienische Missstände durch Abwohnen der container, mangelnde raum- und lufthygienische Qualität mit beginnender Somatisierung und Krankenstandhäufigkeit der Benutzer,“ Stadtmagistrat MA 5 - Gesundheitswersen, Innsbruck, 2009.

[13] EN 13829:2000, Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified)

[14] Forest Products Laboratory, Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.508 p., 2010

[15] Karacabeyli E., Douglas B.: CLT Handbook- Cross laminated timber, CLT Handbook, FPInnovations, U.S. Edition, 2013

[16] Thomé S.: Untersuchungen zur Sorption von Innenraum-Luftschadstoffen durch Wolle, Phd Thesis Faculty of Mathematics, Computer Science and Natural Sciences , RWTH Aachen University, 2006

[17] Roofing Data sheet: Sarnafil ® TS 77-18, Version CH-02.2010, Identification no: 02 09 01 02 200 0 150000

[18] Database: http://www.baubook.at/, 11.02.2013

[19] ISO 6946:2007,Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation method

[20] Stajanca M., Porhincak M., Estokova A., Kapalo P.: The Environmental Based Selection of Building Materials in Office Building, Chemical Engineering Rransactions,Vol. 29,pages 559-564, 2012

[21] IBO Leitfaden: OI3-Indikator Leitfaden zur Berechnung von Ökokennzahlen für Gebäude, IBO - Österreichisches Institut für Bauen und Ökologie GmbHNov. 2011 Ver.3.0

[22] ISO 16000-3:201, Indoor air -- Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air -- Active sampling method

[23] ISO 16000-6:2011, Indoor air -- Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID