SCREENING AND ANALYSING RETROFIT SYSTEMS FOR ZERO ENERGY RENOVATION AND THEIR POTENTIAL APPLICATION IN LIÈGE, BELGIUM

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Abstract
Retrofit systems for Zero Energy Renovation comes energy as the most topical subject in the Belgian construction sector. Concepts and solutions for zero energy renovation are a new topic. Since 2006, Belgium has been striving to achieve the European ambitions of fulfilling the Kyoto Protocol by insulating more effectively and reducing CO^2 emissions associated with the use of fossil fuel for operational and embodied energy in buildings. In 2011, a Belgian decree mandated the construction of nearly zero and nets zero energy buildings by 2020. Following the German PassivHaus Standard performance requirements the Belgian residential sector is aiming to achieve an energy consumption to less than 15 kWh/m^2/year and an onsite renewable energy production up to 60% for every newly construct household. In this, context the study will build on grounded knowledge developed and implemented by the IEA ECBCS Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings. The goal of this research is to screen and select a series of envelope retrofitting solutions. The focused aim is to demonstrate validated envelope prototypes and products of different zero energy, timber frame construction systems and composite components. This will include the comparison of timber retrofit systems with conventional systems. Thus inform and support the decision making of policy makers, municipalities, developers, and architects and building engineers in Belgium.

1 Introduction

The construction sector is the 6th largest contributor to building economy. Next to new construction, renovation has a significant part of the construction sector activities. With the annual increase of the EPBD requirements (K35 in 2014) the compliance with the EPBD requirements increased the new construction prices by 10-12% (excluding inflation rates) between 2007 and 2013 (CCW, 2014). In this context, renovation is becoming more and more the choice for Belgian citizens especially in urban agglomerations. Specially that residential buildings account for more than 70% of the total Belgian building stock (EIA, 2013). In Belgium, the average consumption in households is in the range of 300-350 kWh.m2/year (EIA, 2013). Energy consumption is higher than surrounding countries and 70% higher than the EU average and appears that the sector is less energy efficient than its counterparts in other EU countries (Attia, 2011)(Singh, Mahapatra, & Teller, 2013). The old Belgian building stock, in particular in Wallonia, has being left aging without retrofit plans for years. Therefore, there is a very high potential for retrofit and renovation with a zero energy objective (Attia & Mlecnik, 2012a)(Attia & Mlecnik, 2012b). According to the net zero energy building target building renovation can be achieved through high envelope insulation, air tightness, triple glazing, efficient systems heating and ventilation systems and renewable installations (mainly photovoltaic). Several European exemplary renovation projects demonstrate that it is possible that renovation can achieve the zero energy objective. Building on the knowledge developed and implemented by the IEA ECBCS Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings this research will screen and select a series of envelope retrofitting solutions. The focused aim is to categorize and identify systematically systems and products relevant to façade and roof modules construction. This will include the comparison of timber retrofit systems with conventional systems. Thus inform and support the decision making of policy makers, municipalities, developers, and architects and building engineers in Belgium.

2 Renovation of Liege's Building Stock

Liège is a medieval city situated in the valley of the *Meuse* River and the built environment has a very strong identity. Liège is a major city and the third most populated city of Belgium. As a post-industrial city most of it building stock was built during the first and second industrial revolution. The province is 69.39 Km^2 large with 195.000 inhabitants and has 27 districts or neighborhoods and the building stock in Liège Province can be divided into nine vintages as shown in Figure 1 (Halleux & Lambotte, 2008). Liège is a major city and the third most populated city of Belgium. As a post-industrial city most of it building stock was built during the first and second industrial revolution. Figure 1, represents the distribution of buildings built between 1863 and 2014 (Singh et al., 2013). The province is 69.39 Km^2 large with 195.000 inhabitants and has 27 districts or neighborhoods and the building stock in Liège Province can be divided into nine vintages as shown in Figure 1 (Halleux & Lambotte, 2008). According to Singh et al., 2013, 86% of the building stock in Liège province was built before 1965. The share of buildings before 1863 is 4%, 1863-1879 is 6%, 1880-1899 almost 17%, 1900-1919 20%, 1920-1944 22% and from 1945-1964 is 18%.

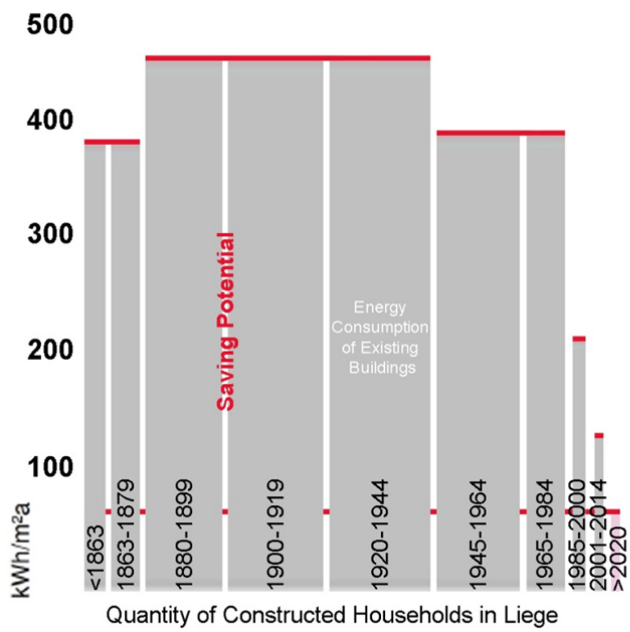

Figure 1 – Distribution of the houses per vintage in Liège (adapted from Singh et al., 2013)

A previous study conducted by the author presents the results of a systematic analysis of 9 neighborhoods of Liège cities' building stock. The analysis include St-Laurent, Center, Laveu, Cointe, Grivegnee, Guilemnins, Vennes, Longdoz, Amercoeur and Outremeuse. Figure 2 presents the analysis outcomes for potential building that could be renovated (Attia, 2015). 45% of the residential buildings are freestanding dwellings, 28% of semi-detached dwellings, 24% terraced or row dwellings and 3% apartment multi-story blocks (INS, 2015b). In the same time rates of new constructions in Liege has been decreasing during the recent 5 years. There are several factors that are the reason for this decrease. One of them is the increase of housing and land prices. Despite the economic crisis of 2008, housing prices has been increasing between 2007 and 2013 between 10-12% (ING). Another one is the change of family structure and ageing population. There is an increase of single parent families, living apart together (LAT) relationships and no partner relationships (Lodewijckx & Deboosere, 2011). Social and cultural life style has changed and is reflected into a demand for flexible urban housing spaces. On the other side, purchasing power of middle class inhabitants has been declining. Therefore, a large

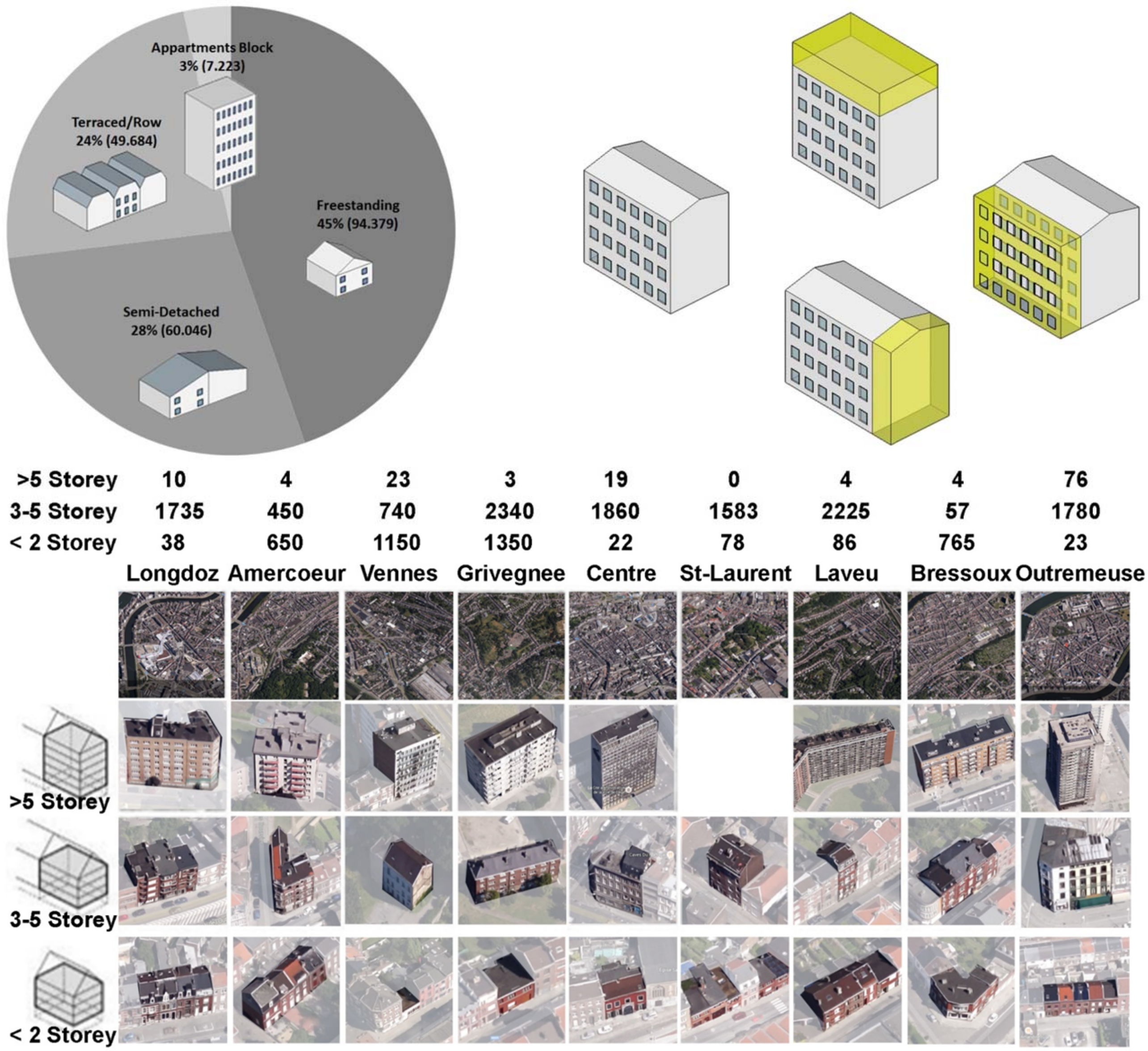

Figure 2 – Potential of renovation of residential buildings in 9 of Liege's' neighborhoods (Attia, 2015) (INS, 2015a)

part of Liege's building stock is vacant and old (Robaye, 2012). In this context, high quality retrofit and densification with timber construction systems emerges as a necessity with specific conditions. For a city like Liege, renovation has to be fast, affordable, of high quality to meet stringent regulations and with a low embodied energy. The overarching aim is to of this study is to screen solutions that can increase the real estate value of housing properties in Liege.

Industrialized pre-fabricated timber units and systems are a promising solution to increase density by stacking up new floors on existing buildings and combine this solution with building renovation. The addition of new floors can finance the expenses of high quality nearly zero energy renovation, provide affordable new housing profiting from the existing infrastructure in Liege. Parallel to the preservation of the city's cultural identity and architectural heritage an old city like Liege must develop a strategy to continue providing its services and meet the needs now and in the future. This cannot be achieved without urban densification. Urban densification in Liege can be achieved by adding new stories, extending building horizontally in rear garden, filling in of vacant land or renovating of exisitng buildings. Without a preparation for this change the city might lose its role cultural endurance. Timber retrofit systems can address structural and functional challenges while enforcing the cities identify. In the same time the city can attain the carbon emission targets mandated by the European Union. Located close to the sources of dense quality wood Liege can be a potential market for pre-fabricated cost and energy efficient timbers retrofit systems.

3 Zero Energy Timber Retrofit Systems

Zero energy timber retrofit systems (ZETRS) can improve the environmental performance of the building stock and in the same time adjust to local architecture and preserve the cultural identity and heritage of Liege. This includes the integration of installation networks for ventilation, heat recovery systems and heating, solar systems, and extending existing building vertically or horizontally. In contrast to total demolition, timber retrofit systems are practical validated solution for urban renewal.

ZETRS in particular are based on proofed concepts for timber frame passive houses. There are several systems that have been developed Central Europe and Scandinavian countries that build up the passive house design concepts and details. The IEA ECBCS Annex 50 focused on the development of pre-fabricated multi-functional roof- and façade modules. Module integrated active components with solar collectors, for electric or hot water supply, are advanced solutions to reach high performance zero energy renovations. Influenced by the industry of prefabricated houses there are several successfully constructed carbon-positive timber houses in Europe. Prefabricated houses, whose parts are assembled in factories, proliferated after the Second World War to meet housing shortages. In 1949 more than 150,000 had been built in Britain. However, cheap bulk associated manufacturing has changed. The evolution of the CNC machines and the rise of new technologies allows the construction of cutting edge zero energy architecture (Sujana, Noguchi, & Barr, 2009). In Canada, the first “net zero-energy” prefab house, the Eco Terra house, has constructed (Attia et al., 2015). Japan a country with a thriving contemporary prefab market provides timber frame insulated zero energy housing modules.

Using prefabricated ZETRS modules can achieve a low conductivity of existing envelopes in compliance with the passive house standard. The integration of triple glazing in the modules and addressing the thermal construction nodes to eliminate thermal bridges is a major advantage of ZETRS modules. Integrated solar cells and solar collectors can be easily embedded in the modules. The challenge remains in the air tightness of the whole panels, tightness of assembly and the junctions and flexibility of installations of electrical mechanical systems. However, in the recent years the quality of the offsite prefabrication allowed a high precision of erection and assembly on site.

4 Review of Zero Energy Timber Retrofit Systems

Traditional renovation concepts in Belgium are based on applying internal or external insulation to existing facades or in the case of cavity wall injecting or blowing insulation in the cavity space. In the case of timber retrofit systems there are two major recognized systems: 1) Timber Frame Systems (Open Box) and 2) Timber Frame Systems (Closed Box) (Mooser, Mérigeaux, Pflug, & Horsch, 2014). For our screening analysis we mainly based our review on the reports of the IEA ECBCS Annex 50 - Prefab Retrofit of Buildings conducted its activities between 2009 and 2011. The aim of the overall IEA project on "Prefabricated Systems for low Energy Renovation of Buildings" is to identify refurbishing solutions for existing residential buildings in order to achieve levels of energy efficiency of 30 – 50 kWh/m² annually. The Annex reported four different approaches on prefabricated renovation modules design and production. The concepts presented have been developed by national teams from Austria, France, Portugal and Switzerland (Kobler et al., 2011). However, we excluded metal retrofit systems. On the other side, we explored the research outcomes of COST Action FP1004 on the mechanical properties of timber, engineered wood products and timber structures. Also action FP0702 on net-acoustics for timber based lightweight buildings and elements. Finally we reviewed the outcomes of the European collaboration project E2ReBuild on industrialized energy efficient retrofitting of resident building in cold climate aiming to demonstrate sustainable renovation solutions that will reduce energy use.

4.1 Timber Frame Systems (Open Box)

The Open Box Timber Frame system is based on standard sized prefabricated façade modules. The module is aligned to be centered with the window center line while vertical ventilation ducts are flanked or embedded on both sides of the window. The system could be described as one sided open timber skeleton of prefabricated modules centered on the window middle axe with technical installation embedded in insulated capsules. From the outside, the façade finish is done on site including cladding or rendering. Standard materials can be used to provide a vapour-permeable external skin. The options include ETICS (external thermal insulation composite system) with rendered finish. From the inside a levelling insulation layer is used to adjust the gypsum board to the existing envelope. Technical installations, mainly ventilation tubes, are connected and encapsulated on site. The same system could be mounted horizontally on flat and sloped roof. The system could be manufactured as one unit covering the entire column of windows. In this sense the system could be design as single modules or as full vertical line of existing openings. Each module could be suspended from the existing wall with metal flats 10 mm thick and 60 mm wide. Depending on te strength of the existing wall the number of metal flats is determined by structrual engineer (Kobler et al. (2011).

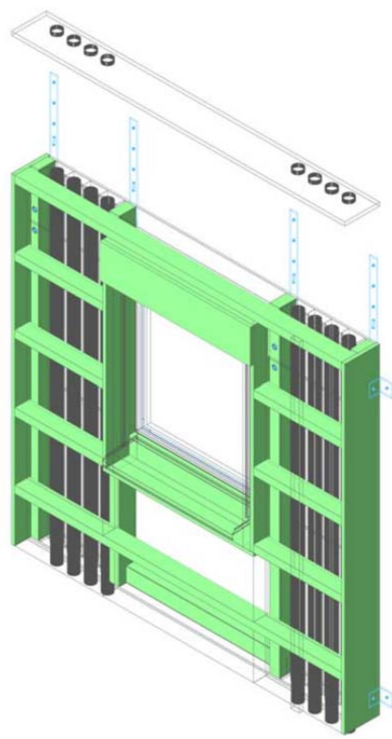

Figure 21: Isometrics showing timber components in a TFS module (Kobler et al. (2011)

4.2 Timber Frame Systems (Closed Box)

4.2.1 Timber-based Element Systems (TES-Energy)

Timber-based Element Systems (TES) are timber based element systems. Between 2008-2010 researchers from Finland, Germany and Norway accomplished a research project titled Timber-based element systems for improving the energy efficiency of the building envelope (TES EnergyFaçade). The goal was to develop a façade renovation method based on large scale, timber based elements for the substantial improvement of the energy efficiency of a renovated building, which would be applicable throughout Europe (Heikkinen, Kaufmann, Winter, & Larsen, 2008). The targeted project buildings are post world war II construction, in particular those earmarked for major renovations in the near future (Heikkinen et al., 2008). The system is based on self supported timber frame skeleton that is fabricated and mounted on site as closed framed box. The system can act as a bearing wall or could fixed in each floor slab. The system is a closed insulated box with embedded window and allowes to apply various cladding materials. Vertical service duct scoukld be eadyly integrated into compartments in the module itself. The system is based on a valiadted protocol and workflow procedure starting from survey, planning, production off-site to assembly on-site. Energy Perfromance is achieved through building perfromance simsulation using BIM models. Prefabrication requires full details on the renovated building. Based on the accuarte mesament and building survey 3D models allow the customisation of TES module and the fabrication off-site

4.2.2 Timber GAP

Another closed box timber frame system is the GAP system. The Gap system is a patented and originates from Austria. The large prefabricated façade modules are fully glazed and can vary covering an area of 3 m by 12 m. Behind the glazed layer is an air gap of solar comb. Windows and technical installations are embedded in the frame system. The modules are piled with a tongue-groove system. The lower starting module is fixed on a bearing steel angle. A timber substructure is fixed on existing building walls to carry the modules.

Figure 4: Layer composition of the basic façade module (Source: gap-solution GmbH)

5 Discussion and Conclusion

This paper presented an initial review on zero energy y for appropriate retrofits of existing buildings for energy efficiency and sustainability. An overview of previous studies related to the investigation and evaluation of energy performance and economic feasibility of different retrofit technologies for building applications is provided.

The concluding remarks and recommendations for case of Liege are as follows.

(1) There is a large body of research on building retrofits available in the public domain. However, existing buildings continue to be upgraded at a very low rate. For instance, existing commercial building stock is currently being retrofitted at a rate of approximately 2.2% per year only.

(2) Previous studies have demonstrated that energy and environmental performance of existing buildings can be improved significantly through appropriate retrofits.
(3) Most previous studies were carried out using numerical simulations. Actual energy savings due to the implementation of retrofit measures in real buildings may be different from those estimated. More research with practical case studies is needed to help increase the level of confidence in potential retrofit benefits.
(4) Whole-of-building retrofit with comprehensive energy simulation, economic analysis and risk assessment is an effective approach to identifying the best retrofit solutions. Further research work and investigation in this regard are needed to facilitate cost effective building retrofits.
(5) To achieve building resilience due to the effects of climate change, more research on low energy adaptive strategies for building applications is needed.
(6) Appropriate selection criteria and weighting factor assignments are essential in the formulation of multi-objective optimisation problems to select the most cost effective retrofit strategies. Major concerns of building owners in regard to retrofits should be carefully considered during the development of the optimisation problem.
(7) Human factors directly affect building energy use. More comprehensive research associated with investigating human factors on building retrofits is needed.
(8) Since investment in building retrofits has a high degree of uncertainty, more research on risk assessment of building retrofits is also needed.

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