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PREFABRICATED TIMBER PANELS APPLICATION POSSIBILITIES FOR THE ENERGY REFURBISHMENT OF RESIDENTIAL BUILDINGS ENVELOPE IN BOSNIA-HERZEGOVINA AND SLOVENIA

Abstract:

System of prefabricated modules installed on the existing building envelope is one alternative solution for deep energy refurbishment of buildings in the European Union. It allows thermal upgrade installation of new parts in the HVAC system. Moreover, some elements of the envelope can be made of renewable materials. This research compares the residential building stock and identifies potential types of buildings for energy refurbishment in Bosnia and Herzegovina and Slovenia. It presents refurbishment possibilities of existing residential building stock in both countries with prefabricated timber panels. It also presents potential obstacles to the wider application of this refurbishment solution.

Keywords: prefabricated timber panels, building envelope, refurbishment, energy saving

МОГУЋНОСТИ ПРИМЈЕНЕ ПРЕФАБРИКОВАНИХ ДРВЕНИХ ПАНЕЛА У ЕНЕРЕТСКОЈ ОБНОВИ ОМОТАЧА ЗГРАДА У БОСНИ И ХЕРЦЕГОВИНИ И СЛОВЕНИЈИ

Сажетак:

Нова рјешења дубоке обнове зграда у Европској унији односе се на постављање префабрикованих модуларних система на постојеће омотаче зграда, који осим топлотног унапређења омотача са грађевинским производима и елементима од обновљивих материјала, такође могу инсталирати и нове дијелове КГХ система. Ово истраживање упоређује градитељски фонд стамбених зграда Босне и Херцеговине и Словеније и идентификује потенцијалне врсте зграда за енергетску обнову. У раду су представљене могућности обнове омотача постојећих стамбених зграда, префабрикованим дрвеним панелима, Босне и Херцеговине и Словеније. Такође, представљене су потенцијале препреке за ширу примјену овог рјешења обнове омотача зграде.

Кључне ријечи: префабриковани дрвени панели, омотач зграде, обнова, уштеде енергије

1. INTRODUCTION

Article 4 of Directive 2012/27/EU on energy efficiency defines the need to develop and adopt a long-term strategy to encourage investment in the reconstruction of housing and commercial, public and private buildings [1]. All EU countries have pledged, including Bosnia and Herzegovina (B&H), which is not yet in the EU, by signing the Energy Community Treaty, to assume the obligations of harmonizing the legal framework with the EU acquits in the energy sector [2]. Accordingly, both countries, Slovenia as an EU member state and B&H as a signatory to that Treaty, adopted the Draft Building Renovation Strategies in 2018 [3] and 2019 [4]. The Strategies do not emphasize the refurbishment of building envelopes by renewable products and materials, but only the use of renewable energy sources. Due to its membership in the EU, Slovenia certifies construction products and materials. Since January 2018, the Environmental Product Declaration – EPD – is recommended, which encourages the use of renewable materials [5]. Green public procurement rules recommend that timber walls contain at least 10% of recycled wood and new buildings contain at least 30% of wood in the total volume of all construction materials used. In addition, high environmental standards for public procurement procedures, including construction of new public buildings and refurbishment of existing ones, are set [6]. This paper presents renovation of buildings with an emphasis on contemporary refurbishment solutions for renewable materials and products, which have been invested in developed countries such as Finland, Norway, Germany, Switzerland and Austria for the last ten years [7] [8]. Although individual materials and elements on the building envelope have a limited economic lifetime (5-25 years), it is estimated that changes to the complete envelope should be made as early as 30 years [9].

Energy refurbishment of the building envelope is considered to be one of the necessary measures to reduce the energy need for heating in B&H and Slovenia (60-70% reduction of the energy need for heating is possible, what will be presented in this paper as well) due to the large amount of building stock built according to the regulative when neither adequate energy performance for buildings nor energy certification was presented. Multiple studies were implemented on this topic and this work tends to present some of which are tackling possibilities of its' implementation in these two countries. B&H and Slovenia had same energy performance for building law legislative up to 1990. However, due to historic circumstances, the changes in law, funds availability, industry capability and international connections enhanced further differences trough time. Still, both countries share exquisite amount of forests capable for providing high quality timber material for envelope refurbishment. Connections between two countries can be established on mutual projects based on ecological approaches in energy refurbishment, thus, this paper aims to present current building stock similarities in both countries and to provide insight of good practice examples from developed countries as well as possibilities of systematic and methodological implementation of those in analysed regions.

The basic strategy for implementing this kind of refurbishment concept should be related to available building stock. Comparative analysis of data on the residential buildings of BiH and SLO was carried out through a methodological framework of the European international project "TABULA". The project investigated typology of residential buildings in accordance with directives 2002/91/EC and 2006/32/EC. The TABULA project, initiated by researchers at the Darmstadt IWU Housing and Ecology Institute, establishes a unique framework for the classification of typology of residential buildings in Europe, with a defined methodology for calculating the energy performance of buildings. Within both projects *Typologies of Residential Buildings in Bosnia and Herzegovina* [10] *and Slovenia* [11] an absolute and specific energy need for heating was calculated for the total of 29 representative residential buildings in B&H and 28 representative residential buildings in Slovenia, which represent six categories of buildings classified into six periods of construction according to the TABULA methodology [12] Figure 1.

In Bosnia and Herzegovina and Slovenia, a building stock that would be adequate for the above-mentioned contemporary method of building renovation has been considered. The overal aim was to expand the offer of building refurbishment methods that can lead to a uniform appearance of buildings and, in general, to the increased use of renewable materials.

Figure 1 *Typology of residential buildings in Bosnia and Herzegovina and Slovenia [13]*

2. SOLUTION FOR THERMAL REFURBISHMENT OF BUILDING ENVELOPE

Every activity in construction should consume raw materials and energy in a responsible way, therefore causing the least emissions. A possible solution is the adoption of a sustainable and ecological refurbishment method should base preferably on renewable materials, such as timber and other bio-based materials, since they have a positive impact on the carbon performance, considering the whole life cycle of a building. [14, 15]

Today, there are known four ways of refurbishment for buildings envelope presented in Figure 2:

- External composite insulation system (ETICS). The common insulation measure is manually brought up insulation panels, covered with reinforced priming material and a plaster coating, which is colored.
- Ventilated façade system. The insulation is brought up between laths or other substructure, fixed with mounting system, covered by various claddings. Entire assembling procedure is carried out manually.
- Partly prefabricated façade system. Assembly of prefabricated substructure is filled with blown-in insulation. Cladding can be integrated in prefabricated system or manually brought up afterwards.
- Prefabricated module system. Fully prefabricated modules are assembled in fabrication hall, transported on-site and mounted on prepared sub-structure onto façade. Serial production is possible.

The first two, which are common and widespread, have been on market since the 1980s, and the other two have been in use since 2010 and they are environmentally friendly.

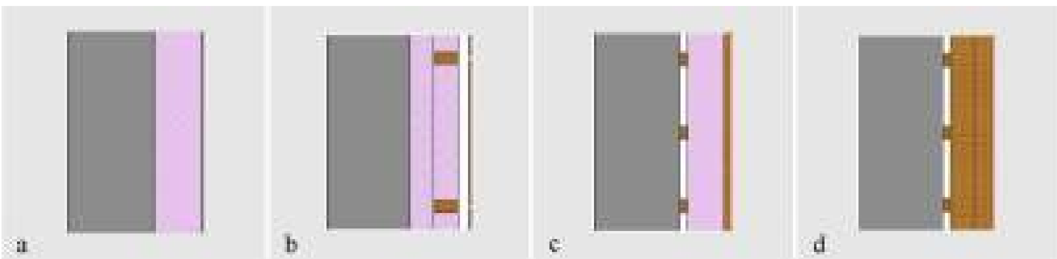


Figure 2 *Solutions of refurbishment façades for existing buildings envelope: a) ETICS, b) Ventilated façade system, c) Partly prefabricated façade system and d) Prefabricated module system [8]*

Although ETICS is currently the most common thermal improvement of building envelopes, it is not future-oriented. The modularity of the prefabricated timber systems, besides significant shortening of renovation time, can be adjusted on-site or in factory conditions. Moreover, it can also be used for various extensions of the building (e.g. upgrades, addition of balconies, corridors) [16]

Prefabricated timber panels are adequate for the deep restoration that is usually required after 45-50 years of use. In this case, apart from interior refurbishment, a new building envelope and building services are required. Prefabricated timber panels can serve in this case to accommodate new distribution pipes for water, sewerage, heating, ventilation and wiring systems [8] (Figure 3). Compared to common insulation solutions, prefabricated panels reduce the disturbance and impact on building users and the neighborhood by faster construction.

The use of prefabricated insulation integrates the building as a whole, ensuring a high-quality execution in a faster time. Prefabricated retrofit systems are standardized in construction layers and joints. They can be combined with each other or with conventional renovation systems. It should be mentioned, however, that during design and development of prefabricated panels, in addition to thermal properties, other aspects such as structural engineering, architecture, building physics, material science, life cycle analysis and life cycle cost should be considered.

Therefore, several parties, such as the thermal specialists which track suitable conditions under environmental changes [17], building physicists which are researching material mutual behavior within complex envelope structures such as moisture control and thermal conductivity, architects capable for managing complex details and detailed designs, HVAC engineers, structural engineers and contractors, shall be involved in the panels' design phase.

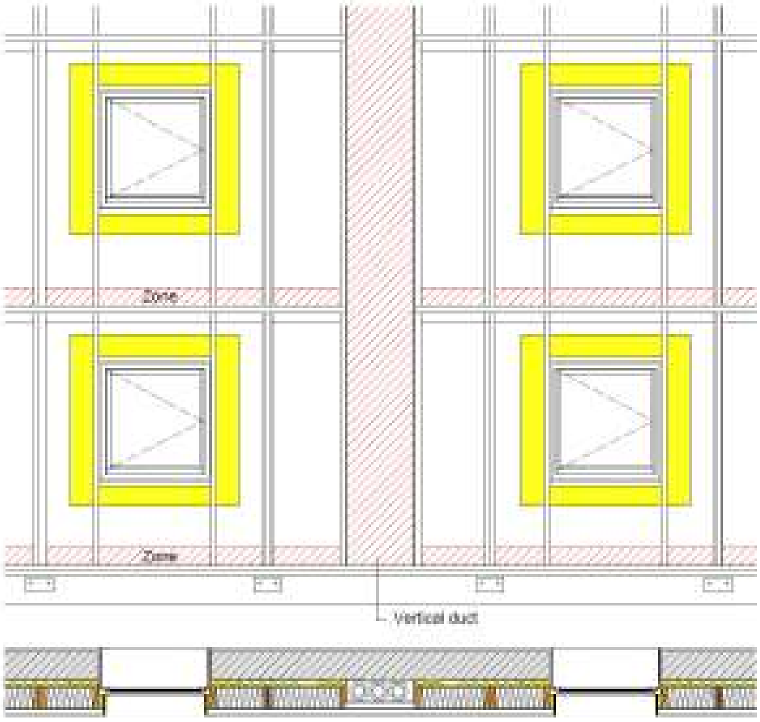


Figure 3 *Scheme of prefabricated system for façade retrofitting [7]*

3. POSSIBILITIES OF REFURBISHMENT IN EXISTING RESIDENTIAL BUILDING STOCK OF BIH AND SLOVENIA WITH PREFABRICATED TIMBER PANELS

During refurbishment of the complete envelope, it is possible to achieve the stated reduction of the energy need for heating, which depends on the building's period of construction (in general, the existence of thermal insulation on the envelope and its thermal characteristics and thickness) and shape factors of the building (the ratio of the area of the envelope and the volume of heated space). The number of buildings with renovation needs is important in order to correctly estimate the number of energy audits. In the case of multifamily houses, the number of apartments within individual buildings and potential number of users are important to correctly calculate economic savings and predict thermal comfort of inhabitants.

3.1. Existing residential building stock

The potential building stock over which the building envelope could be upgraded has been examined through a comparative analysis of data of the housing stock of both countries. In accordance with valid EN ISO 13790 standard, energy requirements of buildings are calculated and expressed in accordance with annual heating energy requirement [16]. Data for Bosnia and Herzegovina were estimated up to 2014 (Table 1) and for Slovenia up to 2011 (Table 2).

Table 1 *Number of residential buildings in Bosnia and Herzegovina [10]*

	SFH	TH	MFH	AB	TOTAL
	Single-family house	Terraced house	Multi-family house	Apartment block	All types
up to 1945	10.773	1.157	450	219	12.599
1946-1960	26.133	1.639	2.462	1.188	31.422
1961-1970	87.596	7.480	3.012	2.164	100.252
1971-1980	194.076	9.257	2.203	2.156	207.692
1981-1991	236.075	5.905	1.116	975	244.071
1992-2014	254.799	6.653	2.725	1.752	265.929
TOTAL	809.452	32.091	11.968	8.454	861.965

Table 2 *Number of residential buildings in Slovenia [11]*

	SFH	TH	MFH	AB	TOTAL
	Single-family house	Terraced house	Multi-family house	Apartment block	All types
up to 1945	140.605	12.974	10.693	930	165.202
1946-1970	91.163	11.383	5.142	885	108.573
1971-1980	82.684	7.505	2.105	1.060	93.354
1981-2001	114.561	8.301	2.248	826	125.936
2002-2008	21.567	2.394	1.152	256	25.369
2009-2011	99	47	14	4	164
TOTAL	450.679	42.604	21.354	3.961	518.598

Bosnia and Herzegovina and Slovenia have a predominantly higher number of buildings / houses intended for individual housing (B&H 97.53%, SLO 95.12%), compared to the number of collective housing buildings. But when looking at the number of housing units within these buildings, the ratio decreases because the number of housing units in individual housing is 66.47% in B&H and 61.78% in SLO, respectively.

In BiH, the total number of individual dwellings is about 841.543, while the number of collective dwellings is around 20.422. When observing the number of dwelling units, 10.764.240 belong to individual dwellings, while 542.945 belong to collective dwellings. In SLO, the total number of individual dwellings is about 493.283, while the number of collective dwellings is about 25.315. When looking at the number of dwelling units, 526.825 belong to individual dwellings, while to collective dwellings the number is 325.868 (Table 3).

Table 3 *Number of residential buildings and apartments in both countries [10] [11]*

	Bosna and Herzegovina		Slovenia	
	number of buildings	number of apartments	number of buildings	number of apartments
SFH and TH	841.543	1.076.240	493.283	526.825
MFH and AB	20.422	542.945	25.315	325.868
Total	861.965	1.619.185	518.598	852.693

B&H has about 39.83% more residential buildings of all types compared to Slovenia, but the number of collective housing buildings in Slovenia is 19.33% higher. The number of housing units in B&H is about 40% higher, which indicates that Slovenia has a larger number of collective housing units of smaller dimensions (MFH). For calculation requirements, it was assumed that the entire building surface used for residential purposes was heated. In countries of the West Balkan region, it was estimated that only 50% of households heated over 50% of the conditioned area [18]; whereas, indicators for EU countries are somewhat better [19]. Therefore, several building categories, especially single-family houses, which according to share in the total surface of the housing stock represent a dominant category, have not met this criteria. This is one of the reasons why the calculated values of energy needs for heating (needed, delivered and primary) deviate from the estimates obtained by the relevant studies and statistical data for Bosnia-Herzegovina and the countries in the region [18]. Basic recommendations for accurate calculations of energy requirements are: use of unified climate data, architectural and construction characteristics of buildings reduced to project values, standardized values that take into account user behavior such as the number of heating hours and internal heat gains and assumed project temperature in the heated space of 20°C.

Energy characteristics of the building envelope and compactness of the structures were determined according to anylysis of representative samples of existing structures type, whose dimensions correspond to the average of the census. Existing condition of the building envelope was determined according to the technical requirements and technological capabilities of a specific construction period, including expert assessment of the building envelope's degradation during service life. The expert estimates for energy need for heating of individual buildings, considering their types and construction periods in B&H and Slovenia, are presented in Table 4.

Table 4 *Energy need for heating representative residential buildings in Bosnia and Herzegovina and Slovenia (kWh/ m²a) [10] [11]*

Residential buildings in Bosnia-Herzegovina						Residential buildings in Slovenia				
	SFH	**TH**	**MFH**	**AB**			**SFH**	**TH**	**MFH**	**AB**
	Single-family house	Terraced house	Multi-family house	Apart-ment block			Single-family house	Terraced house	Multi-family house	Apart-ment block
up to 1945	452.3	183.16	230.7	176.08		up to 1945	516.0	146.80	170.80	226.40
1946-1960	473.9	321.27	219.7	222.30		1946-1970	248.3	183.40	133.50	230.20
1961-1970	464.9	196.42	252.3	194.10		1971-1980	154.0	132.40	147.70	157.50
1971-1980	381.5	199.04	187.0	149.90		1981-2001	148.6	101.10	124.40	125.10
1981-1991	135.9	219.20	189.2	110.87		2002-2008	61.20	80.30	83.90	49.00
1992-2014	127.6	-	65.22	54.81		2009-2011	83.50	78.00	53.30	58.90

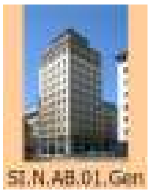
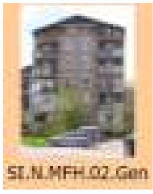
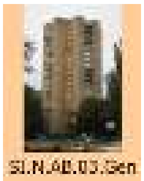
In general, the energy need for heating is decreasing in both countries. Comparing average requirements for all investigated building types, it can be stated that in B&H it decreased by 3.5-3.2 times, while in Slovenia a similar drop was noticed for MFH and AB. The energy need for TH dropped by only 1.6 times, while the highest energy savings can be observed for SFH (over 6 times less comparing investigated timeline).

3.2. Feasibility of prefabricated timber panels application and energy savings

Buildings suitable for the application of prefabricated timber panels are selected according to three criteria: layout, which allows modular division of the façade envelope; period of construction, which requires as a whole the complete thermal improvement of the envelope; and quantity of such buildings within certain typology. Considering the estimate that MFH and AB buildings are suitable for the refurbishment envelope with prefabricated panels in Bosnia and Herzegovina, three construction periods (1945-1960, 1961-1970 and 1971-1980) were selected. The total number of such buildings is about 10.600 MFH and 3.100 AB, while number of residential units are about 179.000 for MFH and 173.500 for AB.

Analyzing the thermal characteristics of buildings in SLO, MFH and AB constructed in three periods (until 1945, 1946-1970 and 1971-1980) are suitable for refurbishment with prefabricated panels. The total number of such buildings is about 17.940 MFH and 2.875 AB, while residential units are about 11.6360 in MFH and 1.295.435 in AB. An estimation of the total envelope area of such buildings is possible by analysis of the typical example for the building presented in Table 5. Each building type has different variations on the shape factor and would require a separate additional analysis of the upgrade envelope.

Table 5 *Representative buildings for refurbishment with prefabricate timber panels from Typology of residential buildings in Bosnia and Herzegovina and Slovenia [13]*

Country	Period	MFH –Multi-family house		AB – Apartment building	
B&H	1946-1960		Reference Floor Area: 489 m^2		Reference Floor Area: 679 m^2
	1961-1970		Reference Floor Area: 585 m^2		Reference Floor Area: 3253 m^2
	1971-1980		Reference Floor AreA: 937 m^2		Reference Floor Area: 2417 m^2
Slovenia	up to 1945		Reference Floor Area: 1160 m^2		Reference Floor Area: 2627 m^2
	1946-1970		Reference Floor Area: 1097 m^2		Reference Floor Area: 2877 m^2
	1971-1980		Reference Floor Area: 2528 m^2		Reference Floor Area: 6774 m^2

Collective residential buildings (MFH and AB), in contrast to individual residential buildings (SFH and TH), have larger envelope areas that need to be renovated. Depending on the type of building (buildings with more of the same slats and floors), structures can be heat-upgraded with the same prefabricated elements of renewable materials, which are also the subject of this analysis.

The annual heat required for heating adequate housing in Bosnia and Herzegovina before and after the implementation of standard renovation measures that reflect legal regulation (achieving U-value for all elements of building envelope) have changed [18, 19]. The measures recently applied are more demanding for the wall and window than prescribed in the FB&H regulation; while in RS, they reach the U-value for windows and do not reach the predicted U-value for walls. Standard improvement measures in typology of residential building defined in accordance with usual measures applied during building reconstruction in the territory of B&H included two actions. The improvement of thermal characteristics of walls and ceilings can be achieved by adding thermal insulation 10 cm thick with λ=0,041W/mK as well as possible replacement of the existing windows with new ones with better characteristics (defined min. U-value 1,60 W/m2K) (Table 6).

Table 6 *Comparative representation of energy required for heating in kWh/m² of representative examples of MFH (multi-family house) and AB (apartment block) buildings, before and after applying standard measures in B&H and Slovenia [13]*

Multi-family house		MFH Before	MFH After	Saving energy
		measure		
B&H	1946-1960	219.7	85.5	134.2
	1961-1970	252.3	111.6	140.7
	1971-1980	187.0	82.2	104.8
Slovenia	up to 1945	170.8	62.4	108.4
	1946-1970	133.5	53.1	80.4
	1971-1980	147.7	51.4	96.3

Apartment building		AB Before	AB After	Saving energy
		measure		
B&H	1946-1960	222.3	79.8	142.5
	1961-1970	194.1	85.6	108.5
	1971-1980	149.9	75.3	74.6
Slovenia	up to 1945	226.4	58.1	168.3
	1946-1970	230.2	58.8	171.4
	1971-1980	157.5	50.00	107.5

In Slovenia, the measures implemented are in compliance with the legislation in force since 2010 [23]. Refurbishment measure includes adding of 15 cm of new thermal insulation on the wall in building with no thermal protection and replacement of the existing windows with new ones having better characteristics (defined minimal U-value 1,40 W/m2K) (Table 6). Depending on the type of building and period in B&H, AB buildings from 1946-1960 have the largest reduction in energy demand, by 64%; while in Slovenia, these are also AB buildings from both periods up to 1970 (decrease of 74%). The impact on such results is influenced by the shape factor of the building as type AB has more clustered housing units than type MFH. Higher energy savings in buildings in Slovenia are justified because of the more rigorous regulations, such as setting of allowed U-values.

Data on the total annual heat required for heating residential buildings were obtained on the basis of statistical data on the total number of buildings and projections of energy consumption. The data from the level of typical buildings to the category level was calculated by introducing the ratio of the average gross area of a certain category to the gross area of a typical building and the ratio of the net to gross area ratios of a typical object. For calculation of national energy balance, only two condensed building typologies (single unit buildings – SFH/SUH and multi-unit buildings – MFH/MUH) were used, thus combining SFH + TH into SFH/SUH and MFH + AB into MFH/MUH, respectively. Furthermore, first to age classes were grouped into single-year class (until 1970), resulting in five age classes.

In B&H, it has been taken into account that some buildings have already been heat-upgraded during these periods. About 16% of façade walls and roofs have been further insulated, and more than 30% of windows were replaced. In Slovenia, it has been taken into account that some buildings have already been heat-upgraded in these periods (15% façade walls, 55% of roofs, 20% of intermediate ceilings towards the attic were additionally insulated and more than 50% of windows were exchanged). Possible energy savings after application of above-mentioned standard measures, in both countries, have almost the same effect (3% difference) (Table 7).

Table 7 *Energy need for heating of residential buildings in Bosnia and Herzegovina and Slovenia before and after standard measueres (MWh/a) [13]*

Bosnia and Herzegovina	**MFH – before**	**MFH - after**	**MFH**
	Multi-family	Multi-family	**Saving energy**
before 1970	1.028.840	328.207	700.633
1971-80	886.510	343.815	542.695
TOTAL	**1.915.350**	**672.022**	**1.243.328**

Slovenia	**MUH – before**	**MUH - after**	**MUH**
	Multi-family	Multi-family	**Saving energy**
before 1970	1.262.000	315.500	946.500
1971-80	356.000	99.680	256.320
TOTAL	**1.618.000**	**415.180**	**1.202.820**

5. POTENTIAL BARRIERS FOR REFURBISHMENT OF THE BUILDING ENVELOPE WITH PREFABRICATED TIMBER PANELS

Even if all buildings can be classified to certain typology, refurbishment with prefabricated timber panels should be adjusted to each building individually. The first four steps presented in Figure 4 allows identification of the most suitable retrofitting strategy.

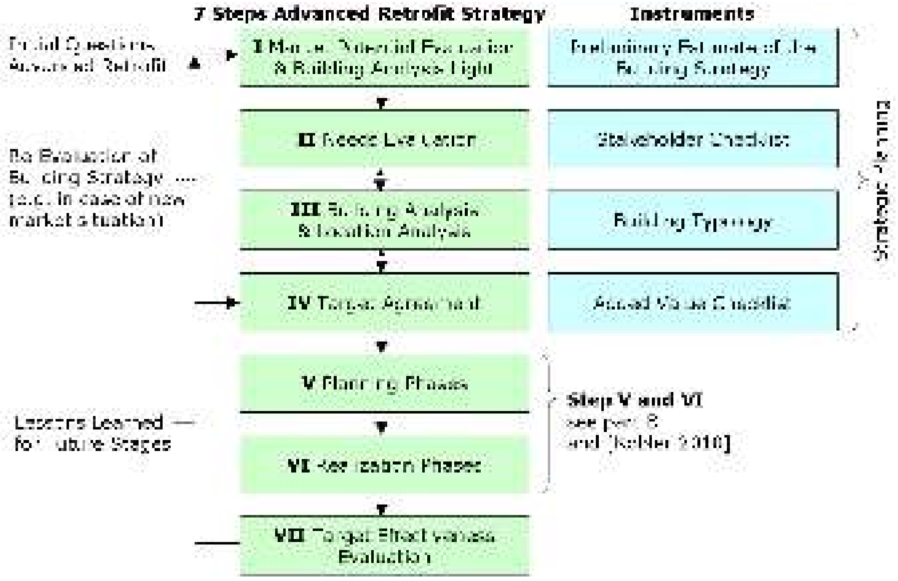


Figure 4 *Strategy of IEA, ECBCS, 2011, for deep refurbishment of building [8]*

In some countries, the use of prefabricated panels with defined dimensions is not a common practice, which cause transportation and installation difficulties. It requires additional training for all people involved in their prefabrication, transportation and installation. Even if execution time and labor are reduced, these systems are still more expensive than common insulation solutions. This represents a challenge because refurbishment costs when using prefabricated timber panels should not be significantly higher than common refurbishment solutions. Even if a lot of research has been carried out in different countries with some successful technological solutions being developed, there has not been a general breakthrough leading to a wider use of such solutions [7]. There are obviously barriers that impede the flow of this know-how toward industry, users and policymakers. Another obstacle might be the higher price of natural renewable materials labelled as “green” or “eco”, commonly perceived products as highly priced. However, this perception may not always reflect reality once a comprehensive cost-benefit analysis is made. The other reason could be the lack of industrial capacity for production of energy refurbishment construction products, elements and systems made from renewable materials. Countries of Eastern and South-eastern Europe frequently limit themselves to the export of raw materials or semi-finished products, due to lack of experience in these regions to run this kind of production in-place. There is a poor exchange of knowledge regarding renewable materials from a cross-border perspective and also between institutions and organizations in the region. Finally, and most importantly, a lack of public awareness about renewable materials for (energy) refurbishments of buildings may also play a role. Very often, only the energy performance of buildings is the focus (also because of its financial consequences for users), and a larger and more holistic view of sustainable refurbishment is missing. In order to overcome above-mentioned obstacles, the following actions are proposed: transfer the knowledge from scientific institutions to industry, implement knowledge at the industrial level to build production capabilities and conduct awareness-raising campaigns aimed at both the public and policy-makers. Only with careful planning and simultaneous execution of these activities, an increase in the use of renewable materials in energy refurbishments might be accomplished.

6. CONCLUSION

In most cases, replacement of the building with a new one can be avoided since deep renovation is more feasible. Every refurbishment project should focus not only on energy optimization of the building but also on increased value for the client: investor, owner and user of the building. The use of prefabricated timber panels in the renovation of buildings might be economically viable if used for deep renovation purposes, due to their multiple roles. Prefabricated elements might serve in addition to thermal retrofitting of the building envelope for building extensions and upgrading. Reducing energy consumption of existing buildings to NZEB (Nearly Zero-Energy Building) is also possible with the use of such systems in the refurbishment of building envelopes.

Bosnia and Herzegovina and Slovenia have almost identical energy savings when comparing refurbishment the entire buildings envelope of the same type (MFH and AB), only for B&H periods from 1945 - 1980 and in Slovenia for all periods until 1980. Respectively, comparing the total energy need for heating condensed buildings in MFH/MUH (MFH+AB), the energy need for heating in B&H is higher than in Slovenia by 15%. The potential energy savings by refurbishment of the envelopes of existing buildings suitable for prefabricated timber panels would be 1.243.328 MWh/a and 1.202.820 MWh/a in Bosnia and Herzegovina and Slovenia, respectively. It is expected that prefabricated timber panels will find their application when sustainable deep refurbishment of buildings using renewable products and materials is required by legislation.

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LITERATURE

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