

Energy-Efficient Renovation Principles for Prefabricated Timber-Frame Residential Buildings

Energetski učinkovita načela obnove montažnih stambenih zgrada s drvenim okvirom

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ABSTRACT • *The timber construction along with the use of suitable and correctly oriented glazing surfaces, whose thermal and strength properties have been considerably improved over the years, represents a great potential in residential and public building construction. However, necessary renovations of the older structures, which present quite a large share of residential fund, should not be overlooked. Moreover, those structures should be adequately energy renovated by the year 2020. Therefore, the key contribution of this paper is the presentation of the available renovation principles, and namely a combination of the improvement of buildings envelope thermal properties, usage of a proper type of installation and share of glazing surfaces in the south-oriented façade, according to affordable investment input. In order to achieve minimal heating and cooling annual energy demand, in the current parametric study, different options were carried out with double-layer and triple-pane glazing, installed in three different types of wall elements, demonstrating the value of optimal glazing surface.*

Keywords: *timber building, glazing, energy efficiency, renovation*

SAŽETAK • *Drvena konstrukcija, uz uporabu odgovarajućih i pravilno orijentiranih staklenih površina čija su toplinska svojstva i čvrstoća tijekom godina znatno poboljšani, velik su potencijal u gradnji stambenih i javnih zgrada. Pritom ne smije biti zanemarena ni obnova starijih objekata, koji čine prilično velik udio u stambenom fondu. Usto ti bi objekti do 2020. godine trebali biti odgovarajuće energetski obnovljeni. Dakle, važan doprinos ovog članka jest predstavljanje raspoloživih načela obnove kao što su kombinacija poboljšanih toplinskih svojstava fasade zgrade, primjena odgovarajućeg tipa instalacija i udjela staklenih površina na južnoj fasadi, ovisno o mogućem investicijskom ulaganju. Kako bi se postigla minimalna godišnja potreba za grijanjem i hlađenjem, u parametarskoj studiji izvedene su različite mogućnosti s dvoslojnim i troslojnim zastakljenjem, ugrađenima u tri različita tipa zidnih elemenata, čime se demonstrira vrijednost optimalnih staklenih površina.*

Ključne riječi: *drvena gradnja, zastakljivanje, energetska učinkovitost, obnova*

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1 INTRODUCTION

1. UVOD

Timber as a material for load bearing construction represents a future challenge for residential and public buildings. Being a natural raw material, timber represents one of the best choices for energy efficient construction since it is also a material with good thermal properties, compared to other construction materials. In addition, it plays an important role in the reduction of the CO₂ emissions (Natterer, 2009), it has good mechanical properties (Vratuša *et al.*, 2011) and ensures a comfortable indoor living climate. Timber construction has better thermal properties than conventional brick or concrete construction methods, even with smaller wall thickness. Considering the growing importance of energy-efficient building methods, timber construction will play an increasingly important role in the future.

Residential buildings represent the biggest share (47 %) of the existing buildings in Slovenia. More than half of them are made of brick (56 %), 16 % of concrete and mixed construction, and the rest made of materials including timber are represented to a smaller extent (Kitek Kuzman *et al.*, 2010). Focusing to the Slovenian timber construction, current rise has been noticed, even though the percentage of new timber buildings in Slovenia is still small regarding the entire new construction, especially in the public buildings sector. In 2010 (SORS), the percentage of newly built pre-fabricated houses, mostly one or two-family, exceeded 15 % and the percentage is expected to increase to 20-30 % over the next five years.

The dominating methods of timber construction in Slovenia include a timber-frame construction, balloon and massive construction. Currently, most Slovenian companies offer houses with timber-frame con-

struction. Timber panel construction has had its own production in Slovenia and Croatia for more than 35 years. The beginnings of pre-fabricated construction started after the second world war, when the barracks were put up for the people who had been left without shelter and those who had migrated from the countryside. Over the past thirty years, timber in Europe construction has undergone major changes. The most important changes introduced are the following (Premrov, 2008): transition from on-site construction to factory prefabrication, transition from elementary measures to modular building and development from a single-panel to a macro-panel wall prefabricated panel system. All of these greatly improve the speed of building.

In timber-frame buildings, the basic vertical load bearing elements are panel walls consisting of load bearing timber frames and sheathing boards. Depending on wall dimensions, one can distinguish between single-panel and macro-panel wall systems. The single-panel was based on the individual smaller elements in dimensions of 1.30 m (1.25 m) x 2.5 m to 2.65 m (Figure 1a). The height of the wall elements met the height of the floor and the length of the ceiling elements the span of the bridged field. The macro-panel system has been developed from the single-panel system in the last two decades and represents an important milestone in panel timber frame building. The aim of the system is to provide whole wall assemblies, including windows and doors, which are totally constructed in a horizontal plane in a factory from where they are transported to the building-site. Prefabricated timber-frame walls, as the main vertical bearing capacity elements, of typical dimensions with a width of 1250 mm and a height of 2500–2600 mm, are composed of a timber frame and sheets of board-material fixed by mechanical fasteners, usually staples, to one or both sides of the timber frame (Figure 1c).

Table 1 Composition of analysed macro-panel (TF 3) and single-panel (TFCL 2, 3) timber-frame wall elements

Tablica 1. Kompozicija analiziranih makropanelnih (TF 3) i jednopanelnih (TFCL 2, 3) zidnih elemenata s drvenim okvirom

TF 3		TFCL 2		TFCL 3 – renovation	
material / materijal	d, mm	material / materijal	d, mm	material / materijal	d, mm
rough coating <i>hrapava obloga</i>	10	wooden planks <i>drvene oplata</i>	22	rough coating <i>hrapava obloga</i>	10
wood fibreboard <i>ploče vlaknatice</i>	60	/	/	mineral wool <i>mineralna vuna</i>	40
/	/	TSS*** / open air gaps / bitumen	0.5	gypsum fibreboard <i>gipsane vlaknatice</i>	15
cellulose fibre / TF* <i>celulozna vlakna</i>	360	TSS*** / open air gaps / TF*	20	mineral wool / TF* <i>mineralna vuna</i>	100
		bitumen sheet cardboard / TF*	0.5		
		TF*MW mineral wool / TF* <i>mineralna vuna</i>	80		
OSB**	15	aluminium foil <i>aluminijaska folija</i>		aluminium foil <i>aluminijaska folija</i>	
gypsum plasterboard <i>gipsana fasadna ploča</i>	12.5	particleboard <i>ploča iverica</i>	13	particleboard <i>ploča iverica</i>	13
		gypsum plasterboard <i>gipsana fasadna ploča</i>	10	gypsum plasterboard <i>gipsana fasadna ploča</i>	10
total thickness, mm <i>ukupna debljina, mm</i>	457.5	total thickness, mm <i>ukupna debljina, mm</i>	146	total thickness, mm <i>ukupna debljina, mm</i>	188
U_{wall} -value, W/m ² K	0.102	U_{wall} -value, W/m ² K	0.48	U_{wall} -value, W/m ² K	0.30

*timber frame / *drveni okvir, **oriented strand board / **ploča s orijentiranim iverjem, ***timber sub-structure / *** drvene podstrukture

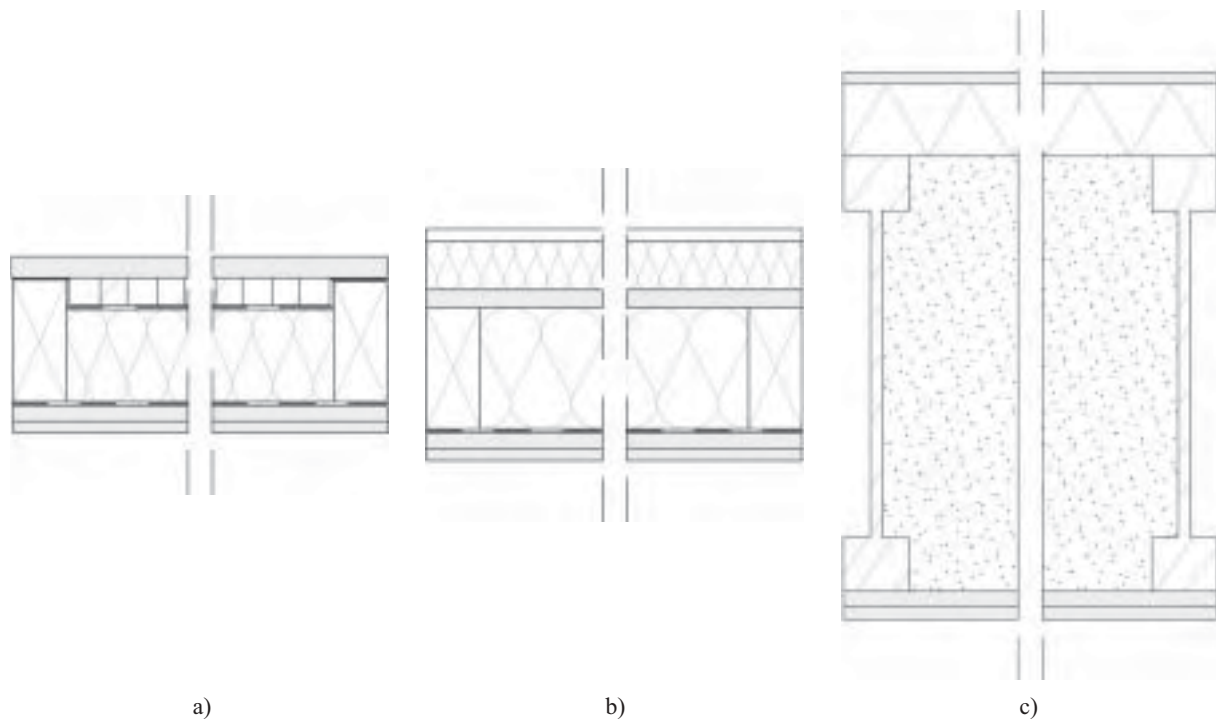


Figure 1 a) single-panel system (TFCL2); b) renovated single-panel system (TFCL 3), c) timber-frame wall element with I-studs (TF 3)

Slika 1. a) jednopanelni sustav (TFCL2); b) obnovljeni jednopanelni sustav (TFCL 3), c) zidni element s drvenim okvirom i I-stupovima (TF 3)

Between the timber studs and girders, a thermal insulation material is inserted whose thickness depends on the type of external wall. Composition of all analysed wall elements is presented in detail in Table 1.

The first single-panel systems in Slovenia were used by Marles and Jelovica. In Slovenia and Croatia there are a few settlements built in the early 70s. For an illustration, Table 2 gives figures of the houses produced by the Company Marles Houses in the period from 1964 to 1987.

Those first pre-fabricated houses had very good thermal properties of external envelope. Thermal transmittance of the best panel types was always much lower than provided by regulations; for example thermal insulation improved by nearly three times from 1963 to 1972, and after 1992 it was almost four times better than specified by the current national regulations (Figure 2). Due to the reduction of energy losses in the newly

built residential structures, the first measure introduced by producers was a gradual reduction of thermal transmittance of external wall elements, resulting in the increase of thickness of the timber-frame wall elements, thus enabling the installation of thicker thermal insulation. Detailed composition of construction of the older single-panel external wall elements, as well as the newer macro-panel system, are explicitly presented in Table 1, with the additional graphic presentation in Figure 1. Figure 2 only shows data until the year 1992, when

Table 2 Number of Marles' pre-fabricated houses from 1964 to 1987 (archive company Marles hiše Maribor).

Tablica 2. Broj Marlesovih montažnih kuća od 1964. do 1987. (arhiva tvrtke Marles hiše, Maribor)

MARLES pre-fabricated houses (purpose) / MARLES montažne kuće (namjena)	Produced number / Broj proizvedenih kuća
residential settlements, terraced houses / stambena naselja, terasaste kuće	590
schools / škole	90
kindergartens / dječji vrtići	360
health centres / domovi zdravlja	40
individual structures / individualni objekti (1964-1999)	10 000

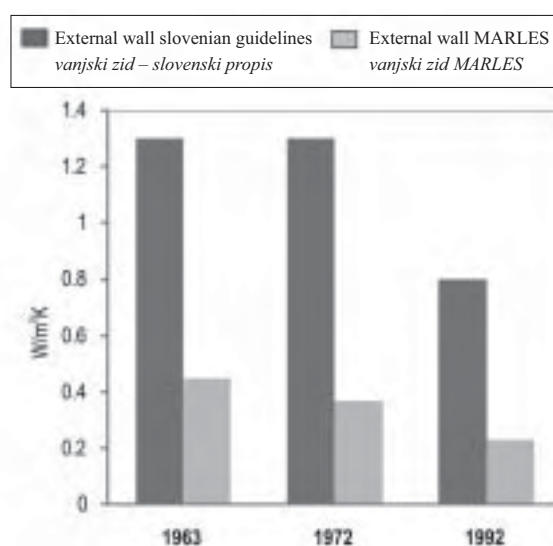


Figure 2 Thermal transmittance of external wall elements - U -value comparison of the Marles' wall with the Slovene regulations in the period 1963 to 1992

Slika 2. Toplinski prijenos vanjskih zidnih elemenata – usporedba U -vrijednosti Marlesova zida sa slovenskim propisima u razdoblju od 1963. do 1992.

the external wall elements met, for the first time, the requirements of the regulations currently applicable in Slovenia regarding energy efficient construction, so that the thermal transmittance of exterior was, for the first time, lower than the prescribed limit value of 0.28 W/m²K, i.e. it has nearly reached the value for light constructions, which is 0.20 W/m²K (PURES, 2010). Therefore, all prefabricated timber framed structures set up before the year 1992 are considered as a fund needing energy efficient renovation by the year 2020. The latter refers to the wide-ranging package on climate change adopted by the European Union, the overall 20-20-20 targets, which are binding for buildings, too. Therefore, the energy performance of the existing buildings has to be improved through a complex process of energy efficient renovation, and likewise a sustainable new construction of energy-efficient buildings with the use of renewables has to be performed.

2 ENERGY-EFFICIENT BUILDINGS

2. ENERGETSKI UČINKOVITE ZGRADE

Researching energy efficiency of buildings is not a matter of the last decade only, since the first intensive studies related to energy and buildings were already carried out in the seventies and eighties of the last century. Many studies focusing on the research of specific parameters influencing energy performance of buildings, such as Johnson *et al.* (1984) and Steadman *et al.* (1987) have been performed since then. Previous research findings indicate that the process of defining the optimal model of a building is very complex. The most important parameters influencing energy-performance of buildings are listed below:

- location of the building and climate data for the specific location,
- orientation of the building,
- properties of installed materials, such as timber, glass, insulation, boards, etc.,
- building design (shape factor, length-to-width ratio, window-to-wall area ratio, building envelope properties, windows properties),
- selection of active technical systems.

According to the Slovene legislative framework, particularly the Energy Act, the system of energy performance certification is defined in *Rules on the methodology of construction and issuance of building energy certificates (2009)*. On the basis of these rules, the classification of energy-efficient houses was carried out, as listed in Table 3.

Table 3 clearly shows that energy efficient structures can be constructed only by an adequate combination of external envelope efficient insulation and high quality glazing installation. Respecting climate change conditions and the subsequent European directions related to energy performance of buildings, the building industry must construct a nearly zero energy house by 2020. Searching for the optimal model of an energy-efficient house has, therefore, become an issue of major importance. Similar concept of optimal solution will consequently have to be introduced into the field of renovation of numerous older buildings, which are far from achieving standards of energy efficient buildings. Therefore, our analysis is directed into the field of prefabricated timber-frame construction, which will try to find an optimal renovation solution as combination of additional layers of insulation on the external wall elements and double-layer or triple-pane quality glazing.

Table 3 Classification of energy-efficient houses on the basis of “Rules on the methodology of construction and issuance of building energy certificates”

Tablica 3. Klasifikacija energetski učinkovitih kuća na temelju *Pravilnika o metodologiji gradnje i izdavanja energetskih certifikata za zgrade.*

Degree / Classification in accordance with the rules <i>Klasifikacija u skladu s pravilima</i>	Generally used classification in practice <i>Općenito primjenjivana klasifikacija u praksi</i>	Q _h * (kWh/m ² a)	Variation of execution / <i>Varijanta izvedbe</i> (according to Praznik and Kovič, 2010)
Class C / <i>klasa C</i>	minimal requirements for low-energy house <i>minimalni zahtjevi za nisko-energetsku kuću</i>	35 – 50 (60)	classical prefabricated construction, conventional heating system, contemporary windows (doors), no central ventilation system / <i>klasična konstrukcija, konvencionalni sustav grijanja, suvremeni prozori, bez središnjega ventilacijskog sustava</i>
Class B2 / <i>klasa B2</i>	low-energy house <i>niskoenergetska kuća</i>	25 – 35	thermally improved building envelope <i>toplinski poboljšana fasada zgrade</i>
Class B1 / <i>klasa B1</i>	better low-energy house <i>bolja niskoenergetska kuća</i>	15 – 25	thermally improved building envelope + HRV** + HP*** / <i>toplinski poboljšana fasada zgrade + HRV** + HP***</i>
Class A2 / <i>klasa A2</i>	passive house <i>pasivna kuća</i>	10 – 15	additionally thermally improved building envelope + HRV + HP / <i>dodatno toplinski poboljšana fasada zgrade + HRV + HP</i>
Class A1 / <i>klasa A1</i>	1-litre house	≤ 10	additionally thermally improved building envelope + HRV + HP + improved U-value of windows (doors) / <i>dodatno toplinski poboljšana fasada zgrade + HRV + HP + poboljšana U-vrijednost prozora (vrata)</i>

* specific annual heating demand / *specifična godišnja potreba*, **heat recovery ventilation / *povrat energije*, ***heat pump / *toplinska pumpa*

3 NUMERICAL STUDY

3. NUMERIČKA STUDIJA

This chapter presents a numerical case study of a two-storey house and its parametric analysis of the impact of the glazing-to-wall area ratio on energy demand. The influence of south oriented glazing area size on heating and cooling energy demand is analysed in the case-study of a single-family house, carried out with three different types of external wall elements:

- a) a new macro-panel timber-frame wall element (TF 3), which satisfies the requirements of a passive house design, of a total thickness of 456.5 mm and U_{wall} value of $U = 0.102 \text{ W/m}^2\text{K}$ (Table 1, Figure 1c),
- b) an old classical single-panel timber-frame wall element (TFCL 2) of a total thickness of 146 mm and U_{wall} value of $U = 0.480 \text{ W/m}^2\text{K}$ (Table 1, Figure 1a).
- c) a renewed timber-frame single-panel wall element (TFCL 3) of a total thickness of 195 mm and a U_{wall} value of $0.30 \text{ W/m}^2\text{K}$, which is developed from the TFCL 2 old system by inserting an additional insulation in the external side of timber frame (Table 1, Figure 1b) – case of renovation.

3.1 Simulation model

3.1. Simulacijski model

Description of the base case study model

The external horizontal dimensions are 11.66 m x 8.54 m for the ground floor and 11.66 m x 9.79 m for the upper floor (Figure 3). The total heated floor area is 168.40 m² and the total heated volume is 437.80 m³.

Climate and orientation

The house is located in Ljubljana with its longer side, the large glazed area, facing south. The city of Ljubljana is located at an altitude of 298 metres, latitude of 46°03' and longitude of 14°31' east. According to

data from http://www.geodetska-uprava.si/DHTML_HMZ/wm_ppp.htm the considered average annual external temperature is 9.8 °C. The average duration of solar radiation is 1712 hours annually.

Construction

Exterior walls are constructed in three different variations, as presented in Table 1. For all analysed wall elements, the timber characteristics are of the same class - C22 according to EN 338. The U -values of other exterior construction elements are in all cases 0.135 W/m²K for the floor slab, 0.135 W/m²K for the flat roof and 0.130 W/m²K for the south-oriented overhang construction above the ground floor area.

Glazing

Two types of glazing were separately considered in the analysis:

- a) a window glazing (Unitop 0.51 – 52 UNIGLAS) with three layers of glass, two low-emissive coatings and Krypton in the cavities for a normal configuration of 4E-12-4-12-E4. The glazing configuration with a g -value of 52 % and $U_g = 0.51 \text{ W/m}^2\text{K}$ assures a high level of heat insulation and light transmission, Gustavsen *et al.* (2007). The window frame U -value is $U_f = 0.73 \text{ W/m}^2\text{K}$, while the frame width is 0.114 m.
- b) a window glazing with two layers of glass, one low-emissive coating and Argon in the cavity for a normal configuration of 4-16-E4, with a g -value of 60 % and $U_g = 1.2 \text{ W/m}^2\text{K}$. The window frame U -value is $U_f = 1.11 \text{ W/m}^2\text{K}$, while the frame width is 0.116 m.

The glazing-to-wall area ratio (AGAW) of the base case in the south-oriented façade is 27.6 %, while the AGAW values of the rest of the cardinal directions are 8.9 % in the north-oriented, 10.5 % in the east-oriented and 8.5 % in the west-oriented façades.



Figure 3 Floor plans of the base-case study model
Slika 3. Tlocrt osnovnog modela proučavanja

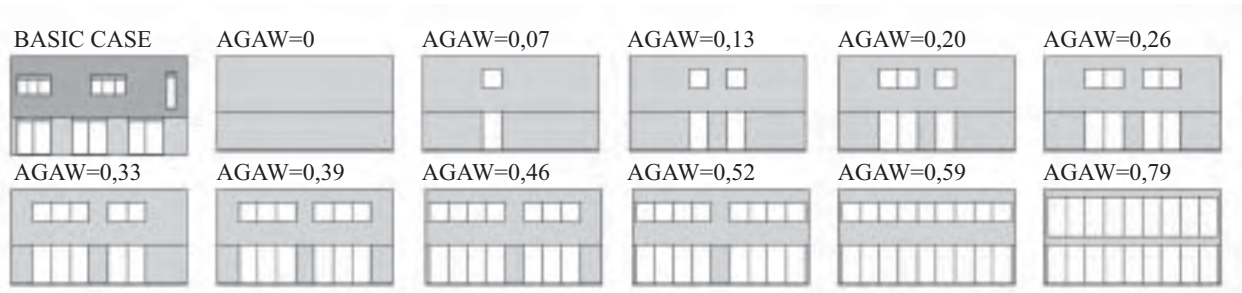


Figure 4 South-oriented façade of the base-case model with schemes of AGAW modification

Slika 4. Južna fasada osnovnog modela sa shemama AGAW modifikacije

Shading

The house is constructed with a south-oriented extended overhang above the ground floor, which blocks the direct solar radiation from entering the ground floor windows to the south during the summer, while it lets it enter in winter when the angle of incidence of the sun is lower. The rest of the windows on the upper floor and those of the east- and west-oriented walls are shaded with external shading devices.

Internal gains and HVAC

The house is equipped with a central heat recovery unit. To prevent overheating in the summer period, night ventilation with cooling through manual window was planned. The interior temperatures were designed to a T_{min} of 20 °C and T_{max} of 25 °C. Domestic hot water generation (DHW) and an additional requirement for space heating are covered by a heat pump with a sub-soil heat exchanger and, to a minimal extent (5 %), by electric heating.

Variable parameters

The influence of the glazing area size on energy demand was only studied in the south cardinal direction. It is known from our previous research (Žegarac, 2011; Žegarac and Premrov, 2011) that the influence of the size of incremental glazing area in other cardinal directions (N, W and E) on the total energy demand is negative, therefore only the south façade of the building is the point of our interest. Modifications of the glazing area size on the south façade were performed in the range of AGAW from 0 % to nearly 80 %. Modi-

fications of the glazing area size were made step by step by adding window elements (frame + glazing) to the totally unglazed façade, as presented in Figure 4.

Description of software and calculation method

The *Passive House Planning Package 2007* was used to perform calculations of energy demand. The software, certified as a planning tool for passive houses, providing a surprisingly accurate description of the thermal building characteristics of passive houses, can also be used for low-energy house design. Practice has shown that the results achieved by PHPP software are very similar to the energy demand measured in operating buildings.

4 RESULTS AND DISCUSSION

4. REZULTATI I RASPRAVA

4.1 Results for macro-panel TF 3 system – new type of passive timber-frame building

4.1. Rezultati za makropanelni TF 3 sustav – nova vrsta pasivne građevine drvene konstrukcije

The results of annual energy demand for heating (Q_h), cooling (Q_k) and the sum (Q_h+Q_k) for the three (TG) and double-layer glazing (DG) as a function of the glazing area size ($AGAW = A_{gl,S} / A_{wall,S}$) for the south cardinal direction are listed in Table 4 and graphically presented in Figure 5.

The above data clearly show that the increase in the size of the glazing surfaces in the south façade has a relatively positive influence on the heating energy demand and shows almost linear behaviour in both cases

Table 4 Energy demand for TF 3 structural system using triple-layer (TG) and double-layer glazing (DG)

Tablica 4. Energetske potrebe za gradbeni sustav TF 3, uz troslojno (TG) i dvoslojno zastakljenje (DG)

TF 3 modification South	$A_{glass,S} / A_{wall,S}$	Q_h kWh/m ² a		Q_k kWh/m ² a		$Q_h + Q_k$ kWh/m ² a	
		TG	DG	TG	DG	TG	DG
M1S	0.767	11.13	23.25	11.01	12.58	22.14	35.83
M2S	0.573	13.91	24.46	6.67	8.13	20.58	32.59
M3S	0.510	14.59	24.48	5.6	6.97	20.19	31.45
M4S	0.446	15.25	24.45	4.62	5.88	19.87	30.33
M5S (opt. for TG)	0.382	16.00	24.49	3.74	4.87	19.74	29.36
M6S	0.319	16.84	24.61	2.96	3.91	19.80	28.52
M7S	0.255	17.81	24.84	2.31	3.05	20.12	27.89
M8S	0.191	18.91	25.18	1.75	2.28	20.66	27.46
M9S	0.127	20.17	25.66	1.30	1.65	21.47	27.31
M10S (opt. for DG)	0.064	21.48	26.16	0.93	1.14	22.41	27.30
M11S	0.000	22.99	26.84	0.64	0.76	23.63	27.60

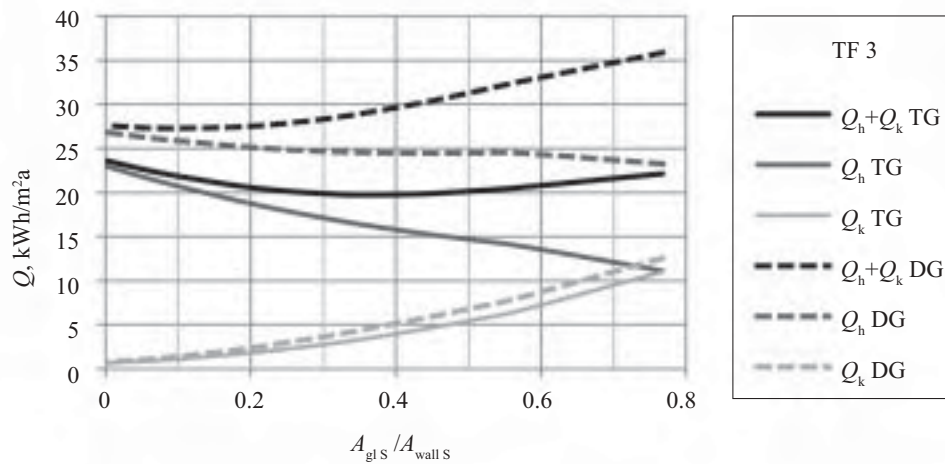


Figure 5 Annual energy demand in the passive TF 3 construction system as a function of AGAW for triple-layer (TG) and double-layer glazing (DG)

Slika 5. Godišnja energetska potreba u pasivnome gradbenom sustavu (TF 3) kao funkcija AGAW za troslojno (TG) i dvoslojno (DG) zastakljenje

of glazing. The function inclination, which physically represents the energy heating benefits, is essentially bigger in the case of the triple-layer glazing. On the other hand, the comparison between patterns of the cooling demand behaviour shows that the glazing type is not so important as heating.

The results for the sum of total energy demand show in both cases an interesting phenomenon related to the optimal point with the lowest $Q_h + Q_k$ demand, which is in the TF 3 construction system by AGAW = 0.382 and results in the energy saving of 3.89 kWh/m²a (or 16.46 %) according to the value by AGAW = 0 (Table 4). The values for the double-layer glazing are essentially different; the optimum point is at AGAW = 0.064 and produces an energy saving of 0.30 kWh/m²a only (or 1.09 %), see Table 4.

The presented results generally match well with the results of the parametric study research on the effect of the glazing type and size on annual heating and cooling demand made by (Ford *et al.*, 2007). The results carried out for the climate in Milan, which are similar to our case, show that there is practically no significant influence of the glazing type on the cooling demand, while there is a strong impact on the energy heating demand. The results of the Swedish study for

the climate in Lund, carried out by Bulow-Hube (2001), also show almost negligible influence of the glazing type on the cooling energy demand.

4.2 Results for single-panel TFCL 2 system – old type of timber-frame building

4.2. Rezultati za jednopanelni TFCL 2 sustav – stara vrsta građevina drvene konstrukcije

In our further research, we analyse the influence of glazing in the south facade of the old classic single-panel frame elements, which were massively installed in the seventies and eighties of the last century and present rather large and important segment of the residential fund, which should certainly undergo adequate energy renovation. Marles' single-panel wall element labeled as TFCL 2, whose geometric and material characteristic are shown in Table 1, with thermal transmittance coefficient $U_{wall} = 0.48$ W/m²K, which is much higher than allowed (see Chapter 3) is taken as an example. The results of the numerical analysis with variable glazing share in the south-oriented facade with the use of triple-pane (TG) and double-layer glazing (DG) are numerically presented in Table 5, and graphically in Figure 6.

Generally, when comparing Figure 5 and Figure 6, the results presented for Q_h , Q_k and the sum $Q_h + Q_k$ show that in the case of the TFCL 2 the glazing type is not so

Table 5 Energy demand for classic single-panel TFCL 2 structural system using three (TG) and double-layer glazing (DG).

Tablica 5. Godišnja energetska potreba za TFCL 2, uz troslojno (TG) i dvoslojno zastakljenje (DG)

TFCL 2 modification South	A_{glass} / A_{wall}	Q_h kWh/m ² a		Q_k kWh/m ² a		$Q_h + Q_k$ kWh/m ² a	
		TG	DG	TG	DG	TG	DG
M1S	0.816	35.43	49.94	10.69	11.6	46.12	61.54
M2S	0.610	42.83	55.02	7.27	8.02	50.10	63.04
M3S	0.542	44.90	56.22	6.40	7.09	51.30	63.31
M4S	0.474	46.93	57.38	5.58	6.21	52.51	63.59
M5S	0.407	49.13	58.65	4.82	5.39	53.95	64.04
M6S	0.339	51.44	60.04	4.12	4.61	55.56	64.65
M7S	0.271	53.88	61.57	3.47	3.89	57.35	65.46
M8S	0.203	56.47	63.23	2.88	3.24	59.35	66.47
M9S	0.136	59.22	65.05	2.35	2.64	61.57	67.69
M10S	0.068	61.98	66.89	1.88	2.11	63.86	69.00
M11S	0.000	64.93	68.93	1.47	1.64	66.40	70.57

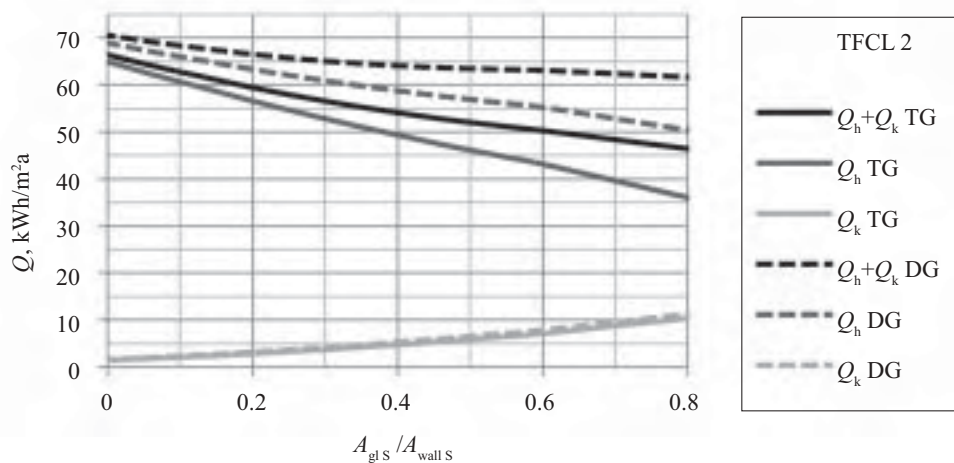


Figure 6 Annual energy demand for classic single-panel TFCL 2 construction system as a function of AGAW for triple-layer (TG) and double-layer glazing (DG).

Slika 6. Godišnja energetska potreba u klasičnome jednopanelnom gradbenom sustavu TFCL 2 kao funkcija AGAW za troslojno (TG) i dvoslojno (DG) zastakljenje

decisive as in the case of TF 3 system. There is practically no influence on the cooling demand at all. In comparison to the TF 3, the functional optimum (lowest $Q_h + Q_k$ value) disappears and the $Q_h + Q_k$ function shows almost linear dependence on AGAW value. The inclination of the function line depends on the glazing type (U_g -value) and it is bigger in the case of the triple-layer glazing (TG). Consequently, in this case, as calculated from Table 5, energy decrease caused by an increase in the total glazing area (measured from AGAW = 0 to AGAW \approx 0.80) represents 20.28 kWh/m²a or 30.54 %. For the double-layer glazing (DG), these values are 9.03 kWh/m²a or 12.80 %. According to these results, it can be concluded that larger glazing area in the south façade significantly increase energy savings (measured in percents), which are higher for the TFCL 2 system than for the new macro-panel TF 3 system.

4.3. Results for single-panel TFCL 3 system – case of renovation

4.3. Rezultati za jednopanelni TFCL 3 sustav – primjer obnove

As presented in Table 1, the system has been fictively developed from the TFCL 2 old system by inser-

ting an additional layer of insulation in the external side of timber frame. The U_{wall} -value, therefore, decreased from 0.48 W/m²K to 0.30 W/m²K. The results of annual energy demand for heating (Q_h), cooling (Q_k) and the sum ($Q_h + Q_k$) for the three (TG) and double-layer glazing (DG) as a function of the glazing area size (AGAW = $A_{gl,S} / A_{wall,S}$) for the south cardinal direction are listed in Table 6 and graphically presented in Figure 7.

The presented results clearly show, just like the TFCL 2, that the glazing type has practically no influence on energy demand for cooling, but the heating function is still essentially bigger in the case of the triple-layer glazing. For the sum of $Q_h + Q_k$, it can be observed that in the case of the double-layer glazing (DG) the optimal point of AGAW appears with AGAW = 0.336 (Table 6). It is interesting that the function dependence on the AGAW is almost constant and the values only vary in the range from 47.36 kWh/m²a at AGAW = AGAW_{opt} = 0.336 to 50.07 kWh/m²a at AGAW = 0. In this case, the total energy demand is practically independent on the size of glazing, which is, of course, very convenient from the economical point of view.

Table 6 Energy demand for fictively improved single-panel TFCL 3 structural system using three (TG) and double-layer glazing (DG).

Tablica 6. Energetska potreba za TFCL 2, uz troslojno (TG) i dvoslojno zastakljenje (DG)

TFCL 3 modification South	$A_{glass} / A_{wall S}$	Q_h kWh/m ² a		Q_k kWh/m ² a		$Q_h + Q_k$ kWh/m ² a	
		TG	DG	TG	DG	TG	DG
M1S	0.810	23.16	36.87	10.80	11.26	33.96	48.13
M2S	0.606	28.45	40.14	7.14	8.14	35.59	48.28
M3S	0.538	29.89	40.79	6.17	7.17	36.06	47.96
M4S	0.471	31.32	41.40	5.28	6.22	36.60	47.62
M5S	0.404	32.86	42.10	4.44	5.30	37.30	47.40
M6S (opt.for DG)	0.336	34.53	42.92	3.69	4.44	38.22	47.36
M7S	0.269	36.35	43.87	3.00	3.64	39.35	47.51
M8S	0.202	38.31	44.95	2.40	2.92	40.71	47.87
M9S	0.135	40.43	46.17	1.87	2.26	42.30	48.43
M10S	0.067	42.57	47.42	1.42	1.69	43.99	49.11
M11S	0.000	44.89	48.85	1.05	1.22	45.94	50.07

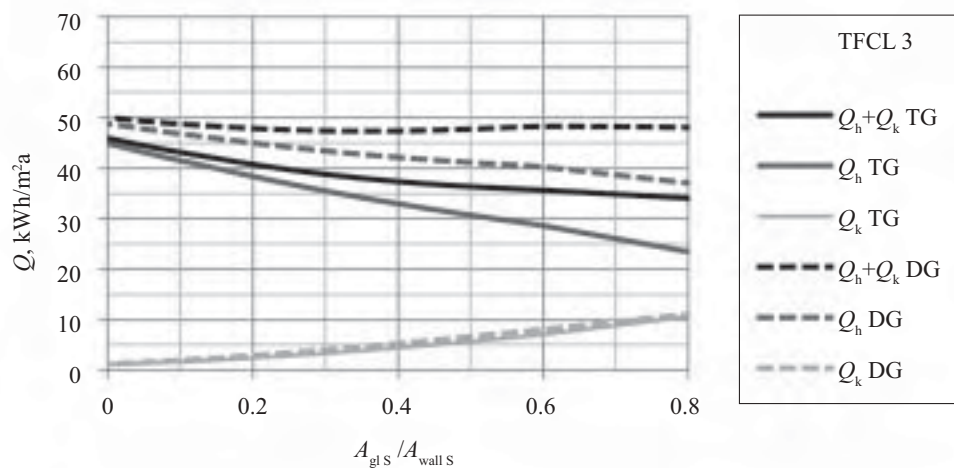


Figure 7 Annual energy demand for the classic single-panel TFCL 3 construction system as a function of AGAW for triple-layer (TG) and double-layer glazing (DG)

Slika 7. Godišnja energetska potreba u klasičnome jednopanelnom gradbenom sustavu TFCL 3 kao funkcija AGAW za troslojno (TG) i dvoslojno (DG) zastakljenje

On the other hand, by using the triple-layer glazing (TG), AGAW does not reach the optimum point, and the enlarged size of glazing still positively effects the total energy demand. Consequently, in this case, as calculated from Table 6, energy decrease caused by an increase in the total glazing area (measured from AGAW = 0 to AGAW \approx 0.80) represents 11.98 kWh/m²a or 26.08 %. The percentage of energy saving is thus not essentially lower as by TFCL 2 (30.54 %). When comparing the values for TFCL 2 (Table 5) and the values for the renewed TFCL 3 system (Table 6), it is important to point out that by inserting an additional insulation the total energy demand was decreased on an average of about 20 kWh/m²a.

Therefore, if approaching a renovation process only from the point of energy saving and not from an economic viewpoint, the use of the triple-layer glazing is definitely a much better solution. For this reason, findings by Žegarac (2011) should be considered, where the generalisation of the treated energy problem was developed on only one single independent variable

(U_{wall} -value). The analysis was performed on the same case study model as in this numerical analyse, using triple-layer glazing only. The possibility of analysing the relationship between the optimal glazing size in south-oriented external wall elements (AGAW_{opt}) related to $Q_h + Q_k$ energy demand and thermal transmittance of the wall element (U_{wall} -value) was demonstrated. The data presented in Figure 8 show the values of AGAW, at which the total sum of heating and cooling demand reaches the lowest value, dependant on the U_{wall} -value of the selected external wall element, independently of the type of construction system.

Figure 8 shows that the optimum or the convergence of the function curves for AGAW_{opt} appears only in systems with the U_{wall} -value \leq 0.193 W/m²K. A higher U_{wall} -value corresponds to a higher optimal share of the south oriented glazing size. By reaching the limiting U_{wall} -value = 0.193 W/m²K, the values for an optimal AGAW converge towards the maximal glazing surface. For the construction systems with the U_{wall} -value $>$ 0.193 W/m²K no optimum or convergence for

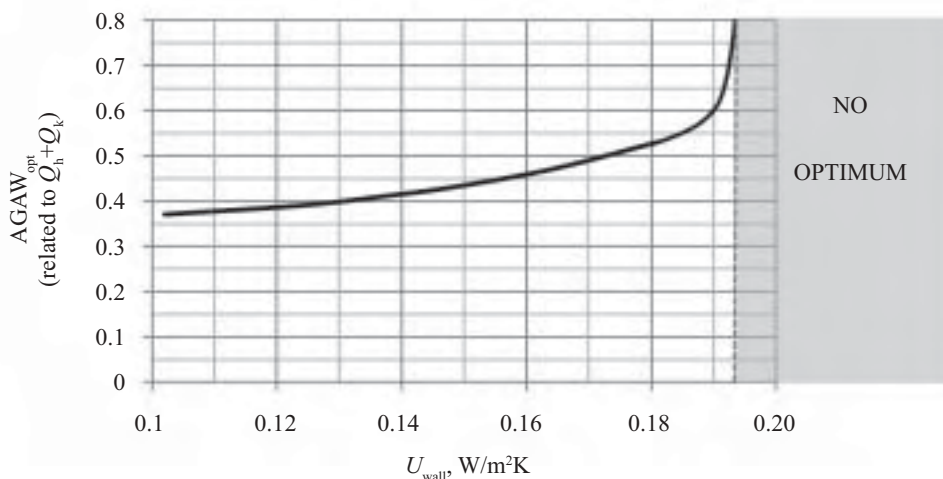


Figure 8 Optimal values of AGAW in the south oriented external wall element as a function of the U_{wall} -value for timber construction systems using triple-layer glazing

Slika 8. Optimalne vrijednosti AGAW u južno orijentiranim vanjskim zidnim elementima kao funkcija U_{wall} -vrijednosti za drvene konstrukcijske sustave koji se koriste troslojnim zastakljenjem

AGAW appear, the lowest Q_h+Q_k is reached at the maximum AGAW value. The whole procedure is widely described by Žegarac Leskovar (2011).

This principle is going to be applicable from a practical point of view in the cases of renovation of old timber houses, where firstly the average U_{wall} -value is reduced with the installation of an additional layer of insulation, and consequently the optimal AGAW value is determined according to the new reduced U_{wall} -value. Finally, the proper size of glazing surfaces can be installed into south-oriented exterior, which contributes to better energy performance of the building.

5 CONCLUSION

5. ZAKLJUČAK

This numerical parametric study shows evidently that in the modern passive prefabricated timber construction (wall system TF 3) double glazing hardly ever pays off regarding energy savings, while triple-layer glazing significantly increases energy savings. Therefore, in order to achieve heating and cooling energy savings in the prefabricated timber-frame structures, built up according to the contemporary passive standards, by installing larger glazing surfaces in the south façade, it is only reasonable to use the glazing of the highest quality, i.e. triple-layer glazing. In the case of the conventional single-panel timber-frame prefabricated timber construction (wall system TFCL 2), which had been used in the seventies and eighties of the last century, nowadays more or less in need of renovation regarding energy efficiency, the type of glazing is much less influential than in the contemporary buildings. Numerical results evidently show that energy savings in the case of triple-layer glazing are higher than in the case of double-layer glazing. However, these differences are much smaller than in the contemporary passive system. In this case, renovation may be a combination of additional insulation and optimal share of south façade glazing. The decision on the choice of the glazing quality is up to the investor, or up to the cost-benefit calculation, i.e. the ratio between the renovation investment and energy savings during future exploitation. As shown in Figure 8, in the case of the triple-layer glazing, from the cost-benefit point of view, it is of prime importance to adequately decrease energy transmittance of the exterior and consequently decrease the share of the glazing surface in the south façade.

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