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# Nearly Zero-Energy Buildings in Croatia: Comparison of Thermal Performance in Different Climatic Regions

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***Abstract***

*In recent years energy efficiency has become one of the most challenging themes for architects around the world. Energy problems and climate changes are more and more in charge of the future development of architecture. Energy-efficient approaches are incorporated into architecture as technical innovations, a particular use of materials based on the location or as utilisation of climatic conditions. Consequently, it is interesting to see what is actually built and how architects approach architectural themes in relation to climate and energy in Croatia.*

*The paper presents a national approach to Nearly Zero-Energy Buildings (nZEB) and way in which to meet the EU 2020 energy and climate policy targets. This research focuses on the evaluation of energy-efficient design strategies of residential buildings in different climatic regions of Croatia.*

***Keywords:*** *Energy Performance of Buildings, nZEB, Residential Buildings, Climate Regions, Croatia*

## 1. Introduction

Energy efficiency has become one of the most challenging themes for architects around the world. Energy problems and climate changes are increasingly becoming in charge of the future development of architecture. New technologies, new materials and changes in social structures have changed the way buildings have been designed and constructed. Today, new energy sources are necessary for architecture to develop, as the housing we build today will remain standing for at least 50 years.

As energy efficiency becomes an important aspect in building design, all participants in the building sector are confronted with numerous regulation changes in the field of energy efficiency. Consequently, it is interesting

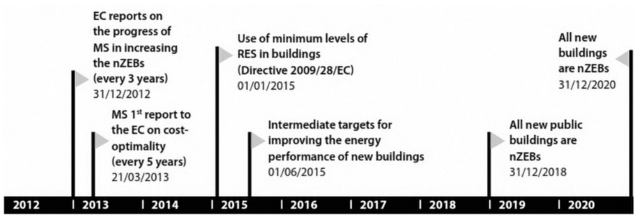


**Fig. 1.** Key years for nearly Zero-Energy Buildings (Directive 2010/31EC). [1]

to see how architects approach architectural themes in relation to climate and energy in Croatia.

The paper does not offer an answer to what energy efficient architecture should be, but rather asks the question: How do we design and build architecture with low energy consumption? The paper brings forth an evaluation of energy efficient design strategies of residential buildings in different climatic regions of Croatia.

## 2. EU 2020 Energy and Climate Policy Targets

The building sector holds high potential for energy demand reduction. As a measure to realize this potential, the European Parliament approved the Directive on the Energy Performance of Buildings in 2010 (*Energy Performance of Buildings Directive 2010/31/EU EPBD*). All the member states of the European Union have an obligation to reduce energy consumption by 20% by the year 2020. Each member state needs to develop a national scheme for achieving the required level of energy savings, in a way that best suits respective national circumstances and is at the same time in line with the common EU goals related to energy savings.

Nearly zero-energy buildings (nZEB) have very high-energy performance. The low amount of energy that these buildings require comes mostly from renewable sources.

The Energy Performance of Buildings Directive requires that after 31 December 2020, all new buildings in the EU will be nearly zero-energy buildings and member states should stimulate the transformation of the existing buildings under refurbishment into nearly zero-energy buildings. For public buildings the deadline is set for 31 December 2018. Although the concept of “nearly zero-energy buildings” is not defined, the objective of this directive is to promote design of buildings with improved energy performance in all EU member states. EU countries have to draw up national plans to increase the number of nearly zero-energy buildings.

### 2.1. National Approach to Nearly Zero-Energy Buildings

Climate and energy are closely bound together. The greater part of the $CO_2$ emitted in Croatia – and in the world in general – comes from energy consumption in buildings. The government has a long-term vision of making Croatia completely independent of fossil fuels. What is required to fulfil this vision is both political actions and actions on the part of individual citizens. The Republic of Croatia’s Energy Strategy is focused on the period before 2020, which corresponds to the period covered by all adopted EU energy strategies. This facilitates the comparison between national goals and EU goals. Buildings account for as much as 42.3% of the total energy consumption. Therefore, reaching the goal will require a concerted effort to reduce energy consumption in buildings. Households are the largest individual energy consumers in Croatia, about 30% of the overall final energy consumption, and the largest users of electricity, over 40% of the overall final electricity consumption. The energy efficiency policy in the residential building sector is based on raising public awareness of possible savings and incentives to plan and build residential buildings in harmony with the principles of energy efficiency [2].

As an EU member state, Croatia has honoured its obligation of establishing the nearly zero-energy building standard (nZEB) and has laid down requirements in the document entitled *Technical Regulation on the Rational Utilisation of Energy and Thermal Insulation of Buildings* (Official Gazette 128/2015) which has been in effect since 1 January 2016 [3]. The Technical Regulation sets the deadline for design of nearly zero-energy buildings, which is 31 December 2020. From that date, all new buildings must be nearly zero-energy, while the deadline for the new buildings that are owned by public institutions is 31 December 2018.

In addition to new buildings constructed in line with the Long-Term Strategy for Mobilising Investment in the Renovation of the National Building Stock of the Republic of Croatia (OG 74/2014), the building renovation model following the nZEB standard was chosen as cost-effective. According to said strategy, apartment buildings and family houses in continental and coastal areas of Croatia are expected to undergo refurbishment in accordance with the standard from 1 January 2021.

Numerical requirements for the annual thermal energy demand for heating and the annual primary energy are different depending on the type and uses of individual buildings. These values have been determined by the Technical Regulation. According to the document, residential buildings are divided into family and apartment houses. A family house is a residential building with the maximum of three individual housing units and with the gross floor area less than or equal to 600 m$^2$. An apartment building is a residential building with four or more apartments.

Nearly zero-energy buildings must also meet the requirement of relying on renewable energy sources for at least 30% of the annual primary energy supply.

**Table 1.** The highest allowed values for new buildings and nearly zero-energy buildings heated and/or cooled to the temperature of 18 °C or more. [3]

| requirements for new buildings and nZEBs | $Q''_{H,nd}$ [kWh/(m$^2$a)] | | | | | | $E_{prim}$ [kWh/(m$^2$a)] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | new buildings and nZEBs | | | | | | new buildings | | nZEBs | |
| building category | continental zone, $\Theta_{min} \leq 3°C$ | | | coastal zone, $\Theta_{min} > 3°C$ | | | contin. $\Theta_{min} \leq 3°C$ | coast $\Theta_{min} > 3°C$ | contin. $\Theta_{min} \leq 3°C$ | coast $\Theta_{min} > 3°C$ |
| | $f_0 \leq 0{,}20$ | $0{,}20 < f_0 < 1{,}05$ | $f_0 \geq 1{,}05$ | $f_0 \leq 0{,}20$ | $0{,}20 < f_0 < 1{,}05$ | $f_0 \geq 1{,}05$ | | | | |
| apartment build. | 40,50 | 32,39+40,58$f_0$ | 75,00 | 24,84 | 19,86+24,89$f_0$ | 45,99 | 120 | 90 | 80 | 50 |
| family house | 40,50 | 32,39+40,58$f_0$ | 75,00 | 24,84 | 17.16+38,42$f_0$ | 57,50 | 115 | 70 | 45 | 35 |

## 2.2. Climatic Conditions in Croatia

Meteorological and climate data are important for modelling energy consumption in buildings. Croatia's climate is determined by its geographical position in the northern temperate zone, which is in terms of relief characterised by a mixture of mountains, plains, forest and a long littoral belt. The topography of Croatia is geographically diverse and climatic conditions are not uniform, which makes analyses and estimations of energy saving possibilities in the residential building sector a complex matter. A specific feature of Croatia's housing stock is rationality, which can be defined in terms of climatic conditions. The northern, north-western and eastern parts of Croatia have a continental climate, and this area, together with the central part of the country which has an alpine climate accounts for 64% of the housing stock. The coastal area (Istria, Kvarner bay and Dalmatia) with a Mediterranean climate accounts for the remaining 36%. The annual amount of energy needed for heating homes therefore varies considerably by location.

The first regulation on thermal insulation of buildings, introduced in 1970 (*Ordinance on Technical Measures and Conditions for Thermal Insulation of Buildings* – Official Gazette of the Socialist Federal Republic of Yugoslavia 35/70) divided the Croatian territory into three building climate zones. Each zone had the highest allowed U-values (W/m$^2$K) prescribed for individual elements of the exterior building envelope. The division stemmed from general climatic conditions and the temperatures in the coldest months of the year. The division had been in use until early 2006, when the new *Technical Regulation on Thermal Energy Savings and Thermal Insulation in Buildings* (OG 79/2005) was implemented. From then on, the Republic of Croatia was divided into two zones. The first included cities and places whose average outdoor air temperature of the coldest month measured at the building's location was ≤ 3°C. The second comprised cities and places whose average temperature of outdoor air of the coldest month at a building's location was >3°C, which in fact corresponded to the continental and costal climate zones. *The Ordinance on Energy Certification of Buildings* (OG 113/2008) introduced a new division into two zones: the continental and coastal climate zones. This division was based on the number of heating degree days in a year. There were cities and places in the continental climate zone that had 2200 and more heating degree days per year, and in the coastal climate zone that had 2200 and less heating degree days per year.

The currently adopted *Ordinance on Energy Audits and Energy Certification of Buildings* (OG 88/2017) has divided the country into zones according to the monthly average outdoor air temperature of the coldest month measured at the location of a building. The continental climate zone now includes cities and places whose average monthly outdoor air temperature of the coldest months measured at the location of the building is ≤3°C. The coastal climate zone includes cities and places whose average monthly outdoor air temperature of the coldest months measured at the location of the building is >3°C

Since 2006, climatic data used for the calculation of energy performance of buildings could be found enclosed in the *Technical Regulation on the Rational Utilisation of Energy and Thermal Insulation of Buildings* (OG 128/2005). Since 2015 meteorological data comprising meteorological values measured at authorised weather stations, which are necessary for calculations based on physical building features in terms of rational energy consumption and thermal insulation, have been published on the web site of the Ministry of Construction and Physical Planning [4]. Considering the great difference between the climate zones in Croatia, the difference can also be discernible in the energy performance of buildings in individual zones.

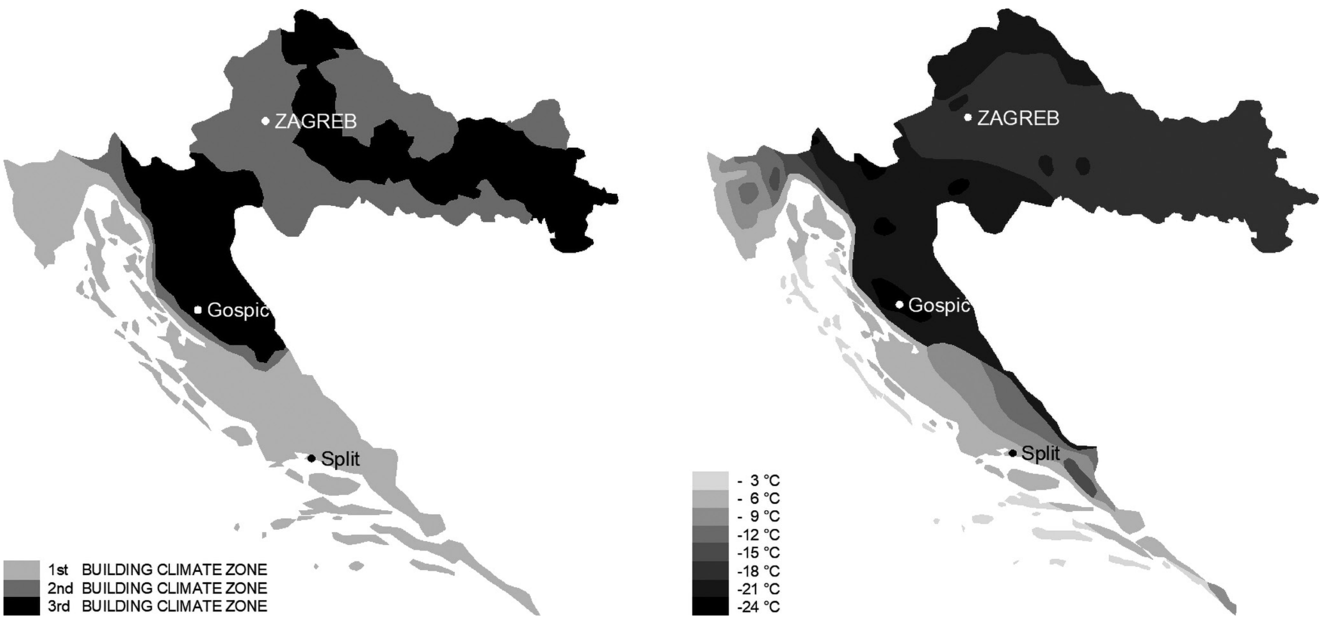


**Fig. 2.** Division of the Republic of Croatia into three building climate zones (left). Outdoor design temperatures (right). [8]

## 3. Chosen Models of Residential Buildings

For the purposes of this study, the authors compared energy performance of a model of the reference family house and a model of the reference apartment building, both of which are located in Gospić and Split, two cities with extremely different climatic features. The lowest temperature in the coldest month in Gospić is -17.2°C, and in Split -3°C. The global irradiance values (southern orientation, 30°) for Gospić is 4930 MJ/m$^2$, and for Split 6295 MJ/m$^2$ [6]. The analysis was done in line with the current Technical Regulation and with the use of En-Cert-HR v.2.37 software.

All the models of the reference buildings have favourable surface-to-volume ratio, which means that the surface area of their external envelope (parts of the building that separate the interior from the exterior and unheated spaces) is relatively small compared to the volume of the heated space of the building. In contrast to buildings with complex plans, compact buildings have smaller surface area through which heat can escape, which consequently reduces heating energy consumption as well as construction prices.

The model of the family house is a one-storey house with a loft and covering 160 m$^2$ of the useful floor area. The dominant orientation of the rooms is on the east-west axis. The south-facing side would be the most suitable for using solar gains in winter. However, statistically, the more frequent are east or west oriented buildings, which have been adopted as the assumed orientation of the models of the family houses and apartment buildings. The apartment building is a four-level structure with four apartments on each floor connected by an inner staircase, all levels are used for housing purposes and apartments covering floor area between 42 and 60 m$^2$. Half apartments have two-sided orientation, and half are only east or west facing [7].

### 3.1. Research Results

The use of the structural elements in the models complies with the requirements of the Technical Regulation (OG 128/2015). The thickness of specific insulation materials corresponds exactly to the values prescribed by the Technical Regulation. Thicker insulation materials would improve energy efficiency, but would also raise the construction price and would result in a longer return on investment. Using thermal insulation twice the size prescribed by the Regulation would decrease the heating energy demand per square unit of the useful floor area Q''H,nd (kWh/(m$^2$a) for the family house in Gospić by

| Models of reference residential buildings in Gospić and Split | |
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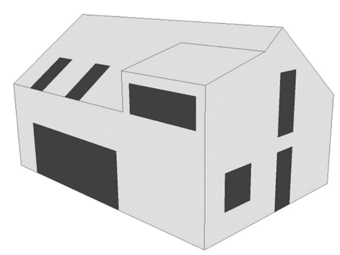
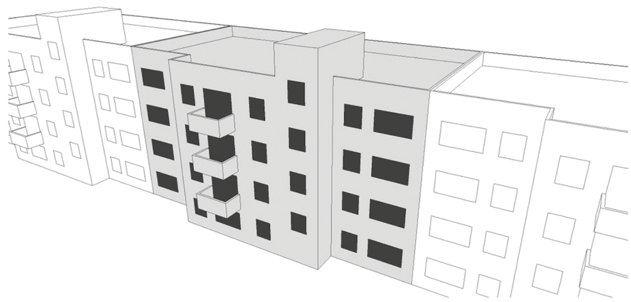
|  |  |
| model of the reference family house<br>surface-to-volume ratio = 0,79 m$^{-1}$<br>usable floor area = 160 m$^2$<br>1 housing unit | model of the reference apartment building<br>surface-to-volume ratio = 0,46 m$^{-1}$<br>usable floor area = 886 m$^2$<br>16 housing units, usable floor area = 42-60 m$^2$ |

**Fig. 3.** Chosen models of the reference family house and the reference apartment building.

**Table 2.** Structural elements: description, real and the highest allowed U-values.

| Structural element | Structural element description | U [W/m$^2$K] | $U_{max}$ [W/m$^2$K] | |
|---|---|---|---|---|
| | | | Gospić | Split |
| Exterior wall | Clay block wall / Reinforced concrete insulated with 12 cm ETICS EPS | 0,27-0,30 | 0,3 | 0,45 |
| Slanted roof | Wooden roof insulated with 12 cm MW between the rafters + 5 cm MW in dropped ceiling | 0,23 | 0,25 | 0,3 |
| Flat roof | RC slab insulated with 15 MW | 0,23 | 0,25 | 0,3 |
| Ground bearing floor | Concrete slab isolated with 8 cm EPS + 2 cm EEPS | 0,33 | 0,4 | 0,5 |
| Windows | PVC window with double-glazed insulated windows one LOW-E pane, filled with argon gas, shutters | 1,28 | 1,6 | 1,8 |

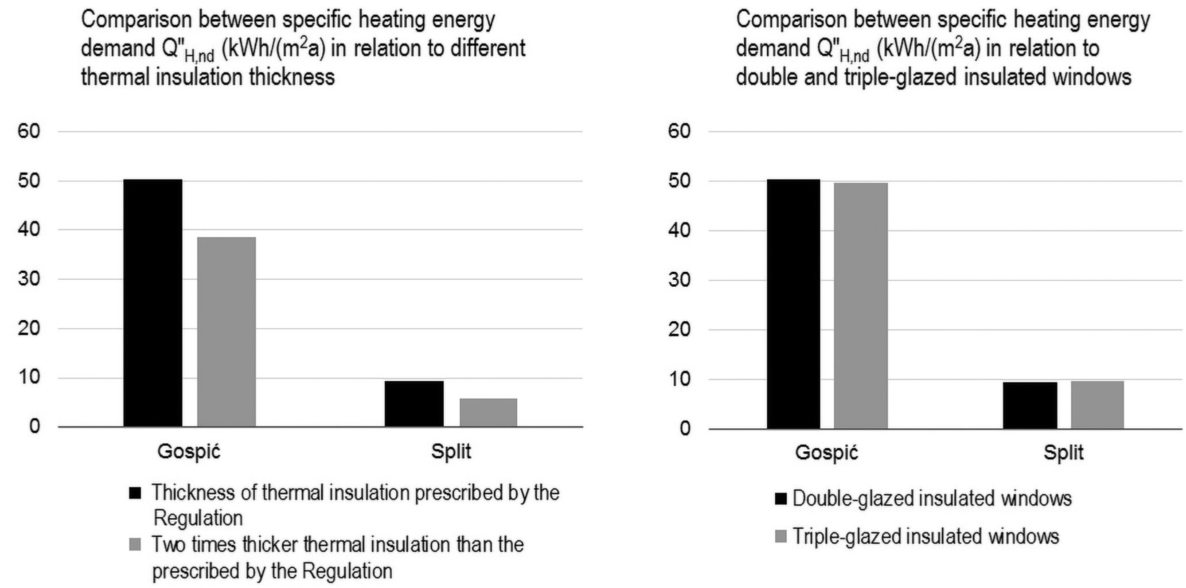



**Fig. 4.** Comparison between specific heating energy demand Q”H,nd (kWh/(m²a) in relation to different thermal insulation thickness and in relation to double and triple-glazed insulated windows on the family houses in Gospić and Split.

23.3% and for the house in Split by 37.8%. Although the percentages represent considerable savings, the difference in the annual cost of heating is still relatively small in relation to the initial investment.

Due to higher prices of windows than walls, the average size of glazed surfaces on family houses and apartment buildings does not exceed the dimensions of most commonly used windows. When the total amount of glazing on building envelopes is relatively low, heating costs, which would be saved by the use of triple-glazed insulated windows, would be very small, which would also result in a long return on investment. For the house in Gospić, the annual savings of heating and cooling would rise by 1.5%, and for the house in Split, the costs would actually increase by 2.5% per year. For buildings with large glazed surfaces and different orientation the impact would be much higher as well as the cost-effectiveness of triple glazing installation.

In addition to heat loss due to transmission through walls, windows, floors and the roof, a considerable amount of heat loss is due to ventilation. In comparison with naturally ventilated family houses, the use of 80% efficient heat recovery ventilation system reduces the thermal energy demand for heating per square unit of the useful floor area for the family house Q”H,nd (kWh/(m²a) in Gospić by 36.2% and of the house in Split by 56.7%.

For the houses with average or low energy consumption such systems are rarely cost-effective, but necessary when lower consumptions is wanted. Cost-effective benefits of using heat recovery ventilation during heating seasons can exceed 20 years for the house in Gospić and 80 years for the house in Split.

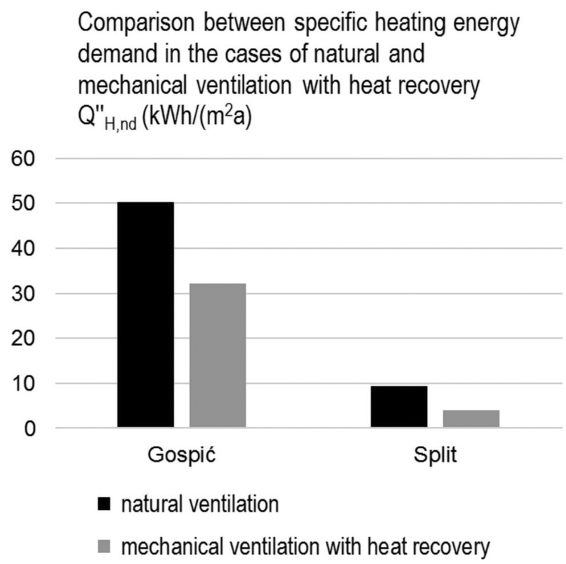



**Fig. 5.** Comparison between specific heating energy demand in the cases of natural and mechanical ventilation with heat recovery in the family houses in Gospić and Split.

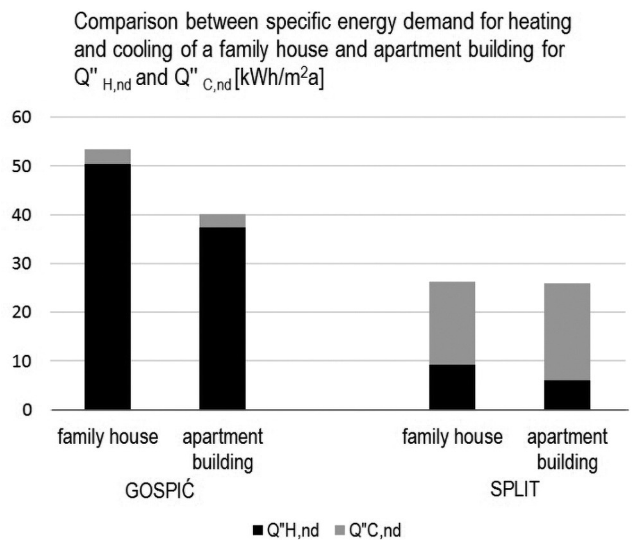



**Fig. 6.** Annual amount of energy needed for heating (Q” H,nd) and cooling (Q” C,nd) per square unit of useful floor area based on real climatic data for a family house and apartment building in Gospić and Split.

**Table 3.** Comparison between the annual thermal energy demand for heating (Q" H,nd) and cooling (Q" C,nd) per square unit of useful floor area based on actual climate data for the family houses and apartment buildings in Gospić and Split.

| Building category | $Q''_{H,nd}$ (kWh/(m$^2$a)) | | $Q''_{C,nd}$ (kWh/(m$^2$a)) | |
|---|---|---|---|---|
| | Gospić | Split | Gospić | Split |
| Family house | 50,36 | 9,27 | 3,10 | 17,06 |
| Apartment building | 37,33 | 5,98 | 2,75 | 19,99 |

In the comparison between the values of annual thermal energy demand for heating per square unit of useful floor area of buildings based on actual climate data Q"H,nd (kWh/(m$^2$a)), it has been shown that the naturally ventilated family house in Gospić (continental climate zone) demands 5.4 times more energy for heating in order to create the same microclimatic conditions as the house in Split (coastal climate zone), which has the same orientation and the same characteristics of construction elements.

In the comparison between the values of the annual thermal energy demand for cooling per square unit of useful floor area of buildings Q"C,nd (kWh/(m$^2$a)), the results show that the family house with an installed cooling system in Split needs 5.5 times more thermal energy for cooling in order to create the same microclimatic conditions.

In a comparison between the total values of the annual thermal energy demand for heating and cooling per square unit of useful floor area for identical family houses, it has been shown that the family house in Gospić needs 2.0 times more thermal energy than the family house in Split.

The comparison between the values of annual thermal energy demand for heating per square unit of useful floor area based on actual climate data Q"H,nd (kWh/(m$^2$a)) has produced the following results. The naturally ventilated apartment building in Gospić in relation to the same apartment building in Split needs 6.2 more thermal energy for heating for the creation of the same microclimatic conditions. When the values of the annual thermal energy demand for cooling per square unit of useful floor area of buildings Q"C,nd (kWh/(m$^2$a)) are compared, the results show that the apartment building with a cooling system in Split needs 7.3 more thermal energy for cooling in order to create the same microclimatic conditions as the identical building in Gospić.

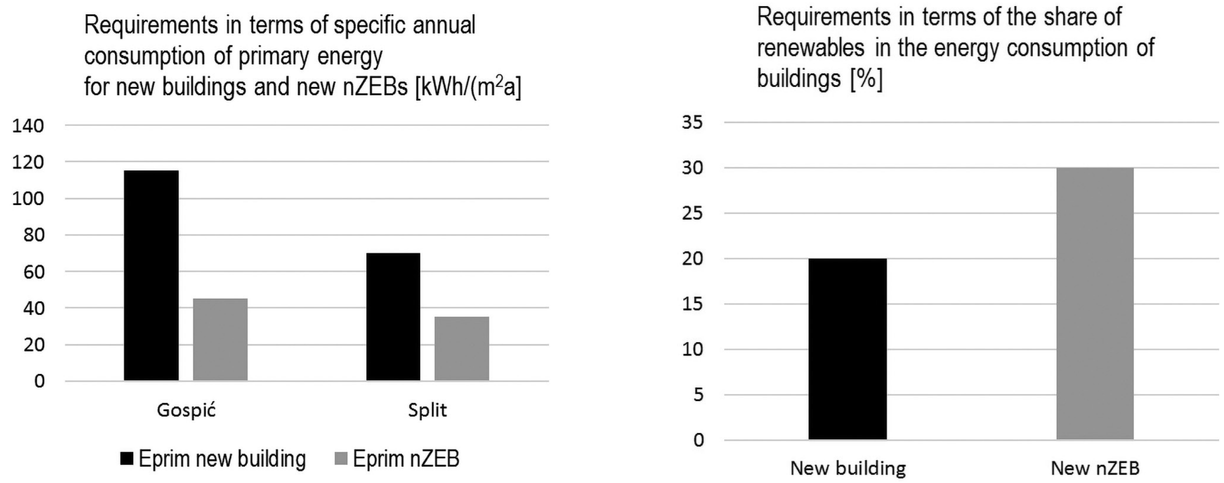



**Fig. 7.** Requirements in terms of specific annual consumption of primary energy for new buildings and new nZEBs [kWh/(m$^2$a] and in terms of the share of renewables in the energy consumption of buildings [%].

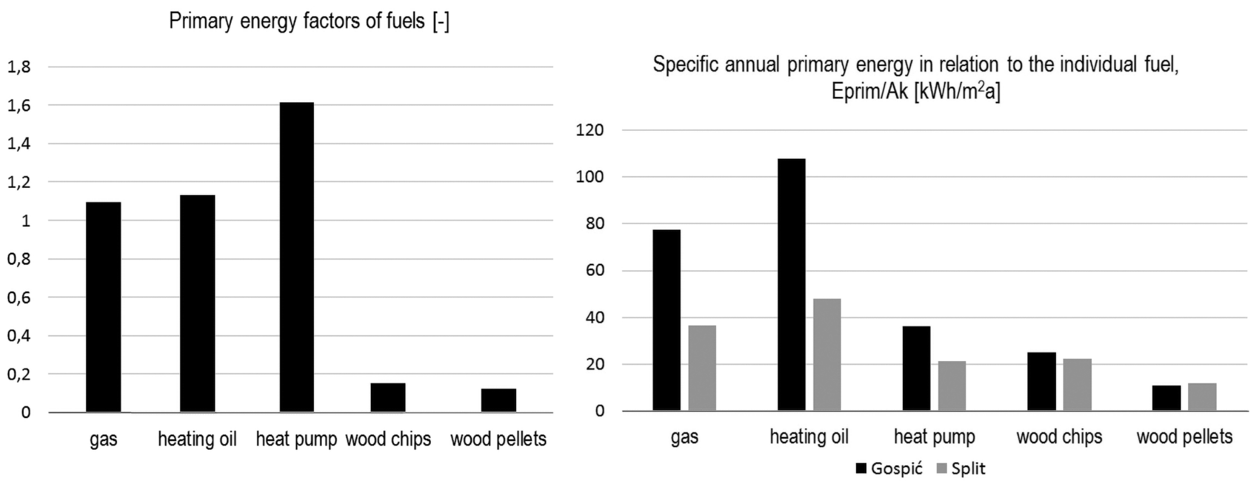



**Fig. 8.** Primary energy factors of fuels and specific annual primary energy in relation to the individual fuel used by family houses in Gospić and Split.

**Table 4.** Versions of the use of energy sources and systems in the cases of family houses and apartment buildings in Gospić and Split, which fit the nZEB criterion according to the Technical Regulation (NN 128/15)

| Use | City | Primary heating systems | Spec. annual delivered energy, $E_{del}$ [kWh/m$^2$a] | Spec. annual primary energy, $E_{prim}$ [kWh/m$^2$a] | Share of energy from renewable sources [%] |
|---|---|---|---|---|---|
| Family house | Gospić | Heat pump | 22,88 | 36,39 | 44 |
| | | Wood pellet boiler | 78,44 | 10,97 | 82 |
| | Split | Heat pump | 13,17 | 21,26 | 45 |
| | | Wood pellet boiler | 38,07 | 11,95 | 69 |
| Apartment building | Gospić | Heat pump | 19,9 | 32,11 | 43 |
| | | Wood pellet boiler | 77,23 | 10,67 | 81 |
| | Split | Heat pump | 14,37 | 23,2 | 45 |
| | | Wood pellet boiler | 40,35 | 13,48 | 68 |

* Central boiler room and preparation of domestic hot water

The comparison between the total values of the annual thermal energy demand for heating and cooling per square unit of useful floor area for identical apartment buildings has shown that the building in Gospić needs 1.5 times more thermal energy than the same building in Split.

In relation to present-day buildings, the Technical Regulation requires that the nZEB has much lower specific annual primary energy a greater share of renewable energy sources in the annual primary energy. The annual consumption of primary energy highly depends on energy resources, and less on the efficiency of the heating system and the buildings' consumption. Figures show comparisons between primary energy factors of certain fuels, specific annual primary energy for the family houses in Gospić and Split in relation to the fuel, a comparison of the share of energy from renewable sources and a comparison between specific delivered energy. [9]

Fuels with a low primary energy factor or the utilisation of highly efficient heating systems will most certainly meet the nZEB requirements determined in the Technical Regulation. These include renewable sources, and heat pumps which become increasingly popular.

Consumption results in relation to the use of different fuels and heating systems are shown in Table 4.

It is clearly evident in Table 4 and Figure 9b that the annual delivered energy demand for heating, cooling and domestic hot water (DHW) has the lowest value when the heat pump is used. Heat pumps use electrical energy only for transferring heat from, or to the environment. That is the reason why they have far greater useful efficiency than the heating systems using thermal energy that is contained in the fuel itself. Heating pumps can be used for heating, cooling and preparation of DHW. The total useful efficiency of such systems varies and is η~3-5, which means that 1 kWh of consumed electrical energy produces ~3-5 kWh of efficient thermal energy.

The initial investment for such a system is considerable, but it is possible to apply for subsidies for the use of renewable energy sources. As heat pumps are highly efficient and use only electricity, this relatively small energy consumption can be compensated with photovoltaic systems especially for cooling and DHW during summer. As well as in case of heat pumps, investment is considerable but subsidies can be applied. Even if subsidies are not possible, in case of Gospić with less irradiation reaching the surface payback period for most optimal photovoltaic systems is around 10 years, and in Split around 6 years.

Figure 10 compares annual electricity production of PV system and electricity consumption of heat pumps for the reference models with applied PV systems.

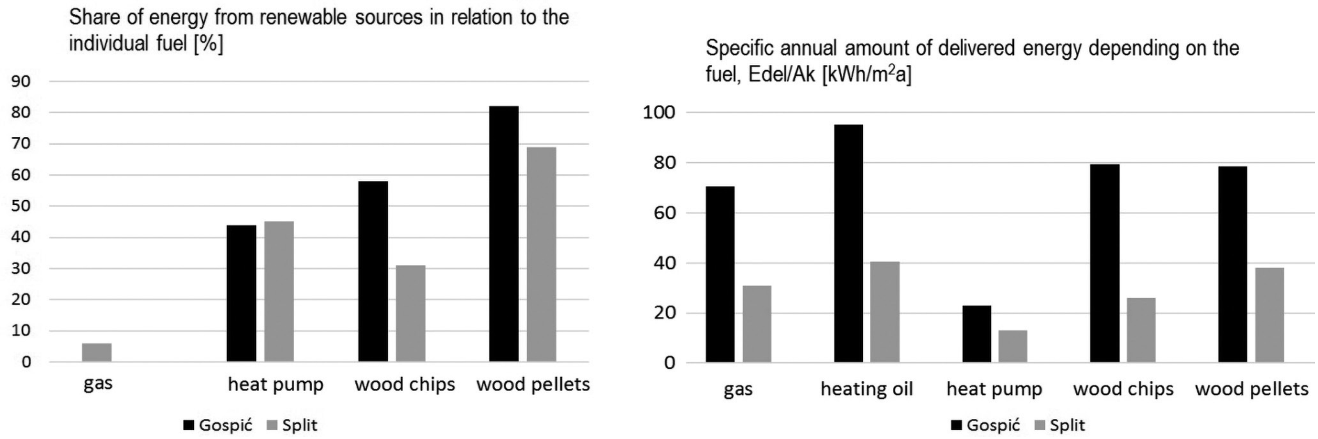
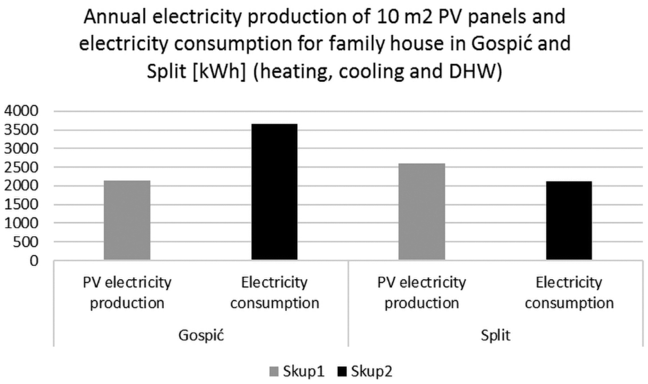



**Fig. 9.** Share of energy from renewable sources in relation to the individual fuel [%] and specific annual amount of delivered energy depending on the fuel used by family houses in Gospić and Split.



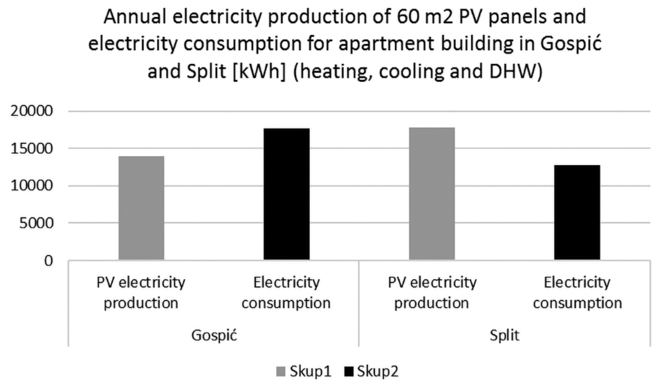




**Fig. 10.** Electricity production and consumption for the family house and apartment building with PV system in Gospić and Split [kWh] (for heating, cooling and DHW).

## 4. Conclusion

Energy efficient and resource conscious approaches are incorporated into architecture in many different ways. It may be a technical innovation, a particular use of materials based on the location or utilisation of climatic conditions.

Energy performance of buildings is highly dependent on the characteristics of the climate zone in which the buildings are located. Considering their position, climate differences between the zones of Republic of Croatia are significant, and that exerts an impact on the energy performance of buildings. The paper has brought froth an analysis of energy performance models of the reference residential buildings (family houses and apartment buildings) which are located in two cities with exceptionally different climate features – Gospić and Split. The analysis entailed calculations and comparisons of values of the annual thermal energy demand for heating, cooling and DHW, specific annual primary energy and specific annual amount of delivered energy in relation to different heating systems.

Considering the heating season, the values of the annual thermal energy demand for the two family houses in two cities show a difference that is five times greater and between the apartment buildings in the cities a difference being more than six times greater. If buildings with an installed cooling system are taken into consideration, the values of the annual thermal energy demand for heating and cooling in the cases of the two houses are 2 times different and the two apartment buildings 1.5 times different.

The comparison between the annual primary energy for different heating, cooling and DHW systems point to the fact that the nZEBs in entire Croatia will predominantly use fuels from renewable sources and high efficient heating systems. These include heat pumps, wood-pellet boilers, solar PV and DHW panels, while systems running on fossil fuels such as coal, heating oil and the like, could only serve as auxiliary systems.

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