The Effect of the U Value in the Energy Performance of Residential Buildings in Greece

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According to the European 2012/31/EE Directive all new buildings until 31/12/2020 and all new buildings occupied by public authorities until 31/12/2018 should be buildings with nearly zero energy consumption. Many countries of the European Union have established legislation with provisions for the energy performance of the buildings with a further goal to reach the nearly zero energy consumption building. In Greece there is a presence of this attempt from the year 2010 with the Regulation of the Energy Performance in Buildings (KENAK, 2010). This was a first attempt for upgrading the energy performance and for establishing the energy inspection of buildings and the relative provisions. In order to achieve the goal and fulfill the requirements of the European legislation a further attempt should be focused in interventions such as lower U value limits in the opaque building elements of the building envelope and windows, in upgrading the energy efficiency of HVAC systems and even the use of renewable sources to cover a percentage of the energy requirements of the buildings. This study aims to evaluate the effect of the reduction of the U value of the opaque building elements in the energy requirements and consumption in residential buildings in Greece, according the climatic zone that is located, as a step closer to the nearly zero energy consumption building.

Keywords: *nearly zero energy building, residential buildings, energy consumption, U value, opaque building elements.*

1. Introduction

Greece is one of the one of the 27 state members of the European Union that has established commitments towards the nearly zero energy building, such as penalties for energy performance requirement non-compliance and incentives for nearly zero energy buildings and for rent of energy efficient buildings (Ó Broin, Mata, Göransson, & Johnsson, 2013). This is presented by the Greek Regulation of Energy Performance of Buildings (KENAK) which with the laws 3851/2010 and 3889/2010 regulates the basic principles of operation and management of energy performance and the basic legislation for Renewable energy.

The Regulation of Energy Performance of Buildings aims to improve the energy efficiency of new buildings in Greece and of the building stock that is consisted of buildings which have incomplete or inadequate thermal protection. Its goal is to reduce the consumption of conventional energy for heating, cooling, air conditioning, lighting and hot water while ensuring the comfort of the interior of buildings. This is achieved with energy efficient design of the building envelope, use of energy efficient building materials and electrical/mechanical equipment, renewable energy sources and CHP systems (TOTEE20701−1, 2010).

With all these efforts for energy upgrading of buildings in line with the Greek legislation in 2013 by Law 4122/2013 the European 2012/31/EE Directive. Its aim is to review periodically the provisions on energy performance of buildings aiming all new buildings until 31/12/2020 and all new buildings occupied by public authorities until 31/12/2018 to be buildings with nearly zero energy consumption. In order to achieve the demanding minimum requirements of the energy performance in buildings, interventions are proposed in the international literature for the energy upgrading of the opaque surface of the building envelope with new lower requirements of the U value and higher thickness of the insulating material or improved window glazing forms (Thalfeldta, Pikas, Kurnitski, & Voll, 2013). Also another approach is the upgrading of the HVAC systems of the building in order to reduce the annual energy consumption with improvements of the efficiency ratio and the automation of the systems. Furthermore the use of renewable sources of energy, such as photovoltaic systems, micro-wind turbines etc. is considered in order to cover a percentage of the energy requirements of the building (Desideri *et al*., 2013).

This study aims to evaluate the attempts of the energy upgrading of the opaque surface of the building envelope in residential buildings in Greece. Furthermore is to quantify the effect of the reduction of the U value of the opaque building elements to the annual primary energy consumption by end use and the annual requirements for heating and cooling depending of the climatic zone that is located.

2. Methods

2.1. The effect of the U value in the consumption of energy

In this analysis was examined the effect of the reduction of the U value in the energy performance of residential buildings and specifically in the annual primary energy consumption by end use and the annual energy requirements for heating and cooling.

The typical construction that was examined is provided for tests by ISO 13790/2008 (table 1) and takes no account of thermal bridges.

Table 1. *Dimensions of construction (ISO13790, 2008)*

Building element	Area (m^2)
West wall	10.08
Window glazing	7.00
North wall	15.40
South wall	15.40
East wall	10.08
Floor	19.80
Roof-ceiling	19.80

The effect of the U value was examined for the opaque building elements that compose the building envelope of residential buildings in Greece (table 2).

Table 2. *Maximum value of thermal transmittance ($W/m^2.K$) per climatic zone in Greece according to the Regulation of Energy Performance in Buildings*

Building elements	Climatic zone A	Climatic zone B	Climatic zone Γ	Climatic zone Δ
External flat or inclined roof	0.50	0.45	0.40	0.35
External vertical building elements	0.60	0.50	0.45	0.40
Windows and doors	3.20	3.00	2.80	2.60
Flooring over pilotis	0.50	0.45	0.40	0.35

To calculate the contribution of the reduction of U value in the consumption of energy the maximum U value (table 2), depending on the climatic zone, of all building elements is imported. Then the U value of the examined element is changing with a descending step 0.05 $W/m^2.K$ while all the other building elements keep their original maximum U value. The procedure is carried out for all the opaque building elements and for the four climatic zones that Greece is divided according to the climatic conditions of each region.

2.2. Climatic zones of Greece according to the Regulation of Energy Performance in Buildings

According to KENAK Greece is divided into four climatic zones depending on the heating degree days of each region. The schematic depiction (Fig. 1) defines the regions located in the four climatic zones, from the warmer (climatic zone A) to the coldest (climatic zone Δ). In each region of a climatic zone that is located in an altitude over 500 meter, is considered to be in the next colder climatic zone than the one they are originally located. All regions located in climatic zone Δ regardless of altitude are included in this zone (TOTEE20701−3, 2010).

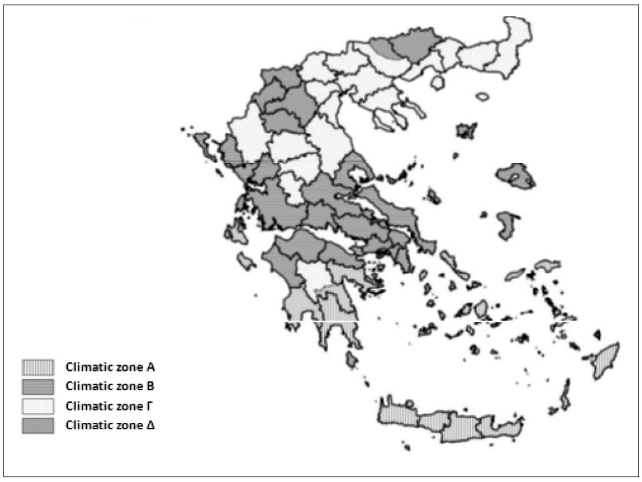

Fig. 1. *Climatic zones of Greece (TOTEE20701−3, 2010)*

2.3. Software TEE KENAK

The software that was used for this analysis is TEE KENAK. This software is used to process the Energy Inspection of buildings and to issue the energy performance certificate. Also is used for calculations and the classification that is required for the study of Energy Efficiency in buildings, boilers and heating and air conditioning systems. It was developed by the Group of Energy Conservation, the Institute for Environmental Research and Sustainable Development and the National Observatory of Athens in the framework of the cooperation program with the Technical Chamber of Greece (TEE). It was created in accordance with European and national standards, the Greek Regulation of Energy Performance of Buildings and the associated Technical Instructions of the Technical Chamber of Greece (TOTEE).

The core of the calculations of the software is based on the pre-existing software EPA-NR (version 1.7.6.19), which was developed under the European Programme Intelligent Energy of Europe, 17th GD EU (EIE/04/125/S07.38651), and has been suitably modified to be consistent with the national requirements in Greece, as provided in Regulation of Energy Performance in Buildings and related Technical Instructions of the Technical Chamber of Greece. The software uses the monthly method for the calculation of the energy requirements and consumption for heating and cooling as it is defined by ISO 13790/2008. This method includes the calculation of the heat transfer by transmission and ventilation, the calculation of the annual energy requirements and energy consumption for heating and cooling and the solar and internal heat gains (ISO13790, 2008).

For the completeness of this analysis it was considered a theoretical heating system with an oil boiler with an efficiency ratio 0.935, a distribution network of hot water for the transmittance of the heat with an efficiency ratio 0.95, terminal units (radiators) with an efficiency ratio 0.93 and supporting units with power 0.1 W/m^2. For the air conditioning system was considered a theoretical cooling system with air-cooled heat pumps with an EER 3.0 and an average monthly coverage of the required cooling energy 0.5, a distribution network with an efficiency ratio 1.0, terminal units with efficiency ratio 0.93 and supporting units with power 0.0 W/m^2 (TOTEE20701−1, 2010).

3. Results

3.1. Vertical building elements of the opaque surface of the building envelope

The reduction of the U value (Fig. 2) in climatic zone A by 0.01 W/m^2.K leads to a reduction in the annual energy requirements for heating 0.518 kWh/m^2 and in climatic zone B 0.562 kWh/m^2. The same change of the U value leads to a reduction of 1.032 kWh/m^2 in zone Γ and 1.364 kWh/m^2 in zone Δ (table 3).

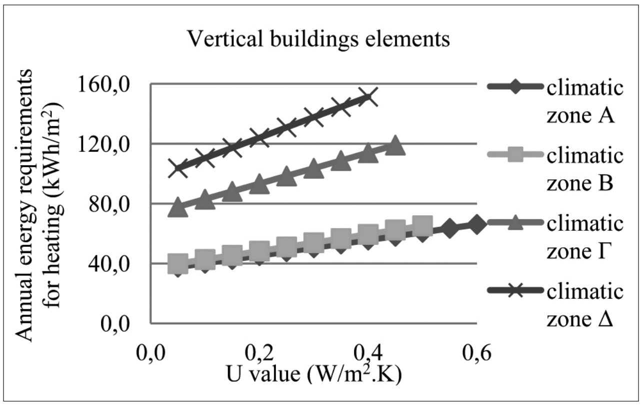

Fig. 2. Reduction of annual energy requirements for heating for the change of U value of the vertical building elements for the four climatic zones

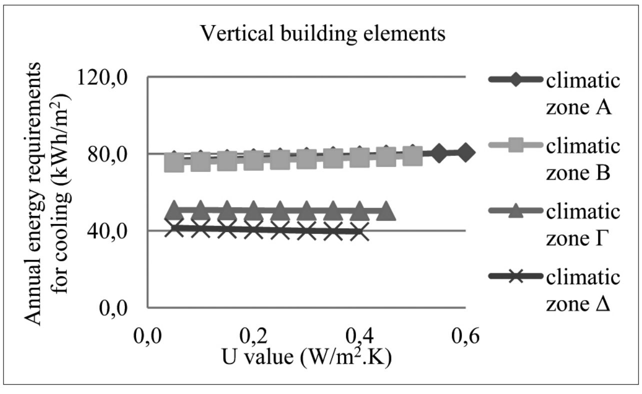

Fig. 3. Reduction of annual energy requirements for cooling for the change of U value of the vertical building elements for the four climatic zones

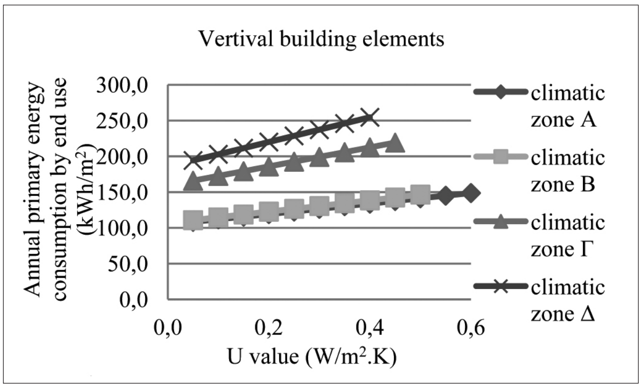

Fig. 4. Reduction of annual primary energy consumption by end use for the change of U value of the vertical building elements for the four climatic zones

The annual energy requirements for cooling appear to have small changes in all four climatic zones between the original and the final U value (Fig. 3). A decrease 0.075 kWh/m^2 is observed in climatic zone A and a decrease 0.073 kWh/m^2 in climatic zone B. An increase 0.011 kWh/m^2 is observed in climatic zone Γ and 0.057 kWh/m^2 in climatic zone Δ for the reduction of the U value by 0.01 W/m^2.K (table 3).

The reduction of the U value in climatic zone A (Fig. 4) by 0.01 W/m^2.K leads to a reduction in the annual primary energy consumption by end use 0.733 kWh/m^2 and in climatic zone B 0.793 kWh/m^2. In climatic zones Γ and Δ the same change of the U value leads to a reduction of 1.331 kWh/m^2 in zone Γ and 1.725 kWh/m^2 in zone Δ (table 3).

Table 3. Effect of the reduction of the U value by 0.01 W/m^2.K to the annual energy requirements for heating and cooling and the annual primary energy consumption by end use

Vertical building elements	Reduction of U value 0.01 W/m^2.K			
	Climatic zone A	Climatic zone B	Climatic zone Γ	Climatic zone Δ
Annual primary energy consumption by end use (kWh/m^2)	-0.733	-0.793	-1.331	-1.725
Annual energy requirements for heating (kWh/m^2)	-0.518	-0.562	-1.032	-1.364
Annual energy requirements for cooling (kWh/m^2)	-0.075	-0.073	+0.011	+0.057

Evaluation

As it is observed (Fig. 5) the reduction of the energy requirements for heating follows about the same change as the effect of the reduction of the U value between the four climatic zones and for a point of reference the values of climatic zone A. From the transaction from climatic zone A to B the changes in these parameters are minor with a percentage 6.6–8.5 %. From climatic zone A to Γ a difference is observed of 99.4–105.6 % and from climatic zone A to Δ 163.4–173.2 %.

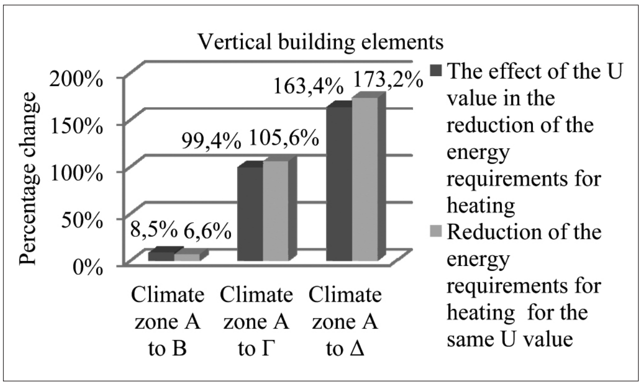

Fig. 5. *The reduction of the U value and of the annual energy requirements for heating between the four climatic zones*

Between the reduction in the primary energy consumption by end use and the effect of the U value a significant difference is observed in the percentage change (Fig. 6). The percentage change of the effect of the reduction of the U value from climatic zone A to B is 8.2%, from zone A to Γ 81.7% and from zone A to Δ 135.5. The average percentage change in the reduction of the primary energy consumption by end use from climatic zone A to B is 2.9%, from zone A to Γ is 56.5% and from zone Γ to Δ is 85.8%. This can be explained by the influence of a number of other parameters to the final calculation of the primary energy by end use such as the technical parameters of the heating and cooling system (efficiency ratio, EER, automation of HVAC systems etc.) and the indicators used for the calculation of the contribution of the form of energy source.

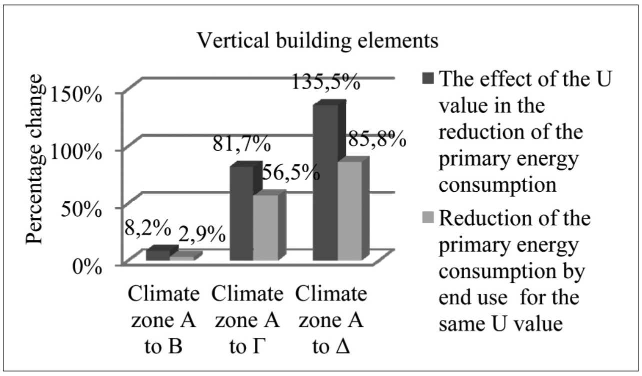

Fig. 6. *The reduction of the U value and of the annual primary energy consumption by end use between the four climatic zones*

3.2. Building element flooring over pilotis

The reduction of the U value in climatic zone A (Fig. 7) by 0.01 W/m^2.K leads to a reduction in the annual energy requirements for heating 0.227 kWh/m^2 and in climatic zone B 0.246 kWh/m^2. In climatic zones Γ and Δ the same change of the U value leads to a reduction of 0.444 kWh/m^2 in zone Γ and 0.574 kWh/m^2 in zone Δ (table 4).

In the annual energy requirements for cooling (Fig. 8) an increase 0.024 kWh/m^2 is observed in climatic zone A, in climatic zone B 0.025 kWh/m^2, in climatic zone Γ 0.045 kWh/m^2 and in climatic zone Δ 0.058 kWh/m^2 for a reduction of the U value by 0.01 W/m^2.K (table 4).

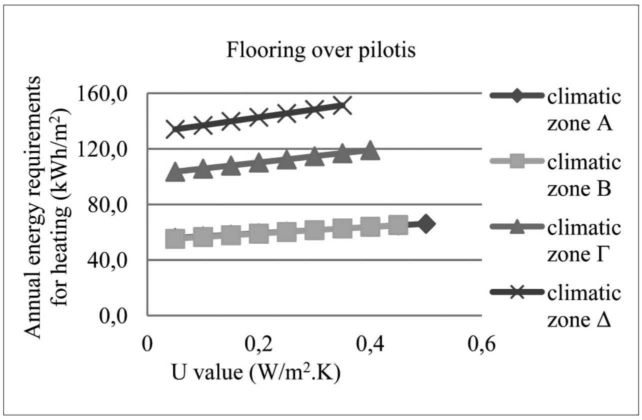

Fig. 7. *Reduction of annual energy requirements for heating for the change of U value of the building element flooring over pilotis for the four climatic zones*

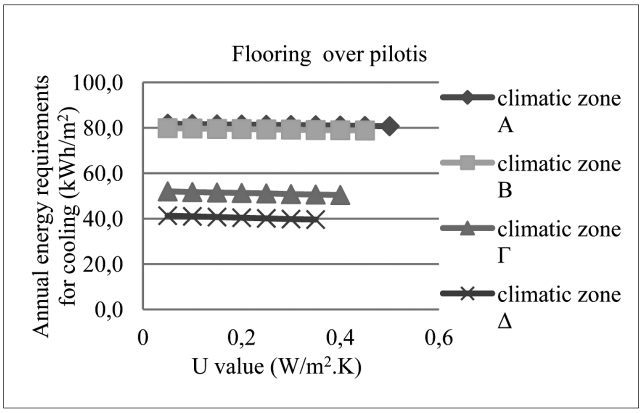

Fig. 8. *Reduction of annual energy requirements for cooling for the change of U value of the building element flooring over pilotis for the four climatic zones*

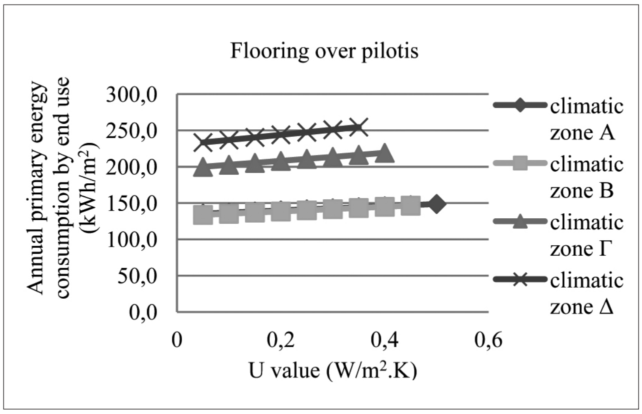

Fig. 9. *Reduction of annual primary energy consumption by end use for the change of U value of the building element flooring over pilotis for the four climatic zones*

The reduction of the U value in climatic zone A by 0.01 W/m^2×K leads to a reduction in the annual primary energy consumption by end use (Fig. 9) 0.293 kWh/m^2 and in climatic zone B 0.320 kWh/m^2. In climatic zones Γ and Δ the same change of the U value leads to a reduction of 0.550 kWh/m^2 in zone Γ and 0.706 kWh/m^2 in zone Δ (table 4).

__Table 4.__ Effect of the reduction of the U value by 0.01 W/m^2.K to the annual energy requirements for heating and cooling and the annual primary energy consumption by end use

Flooring over pilotis	Reduction of U value 0.01 W/m^2.K			
	Climatic zone A	**Climatic zone B**	**Climatic zone Γ**	**Climatic zone Δ**
Annual primary energy consumption by end use (kWh/m^2)	-0.293	-0.320	-0.550	-0.706
Annual energy requirements for heating (kWh/m^2)	-0.227	-0.246	-0.444	-0.574
Annual energy requirements for cooling (kWh/m^2)	+0.024	+0.025	+0.045	+0.058

Evaluation

As it is observed (Fig. 10) the reduction of the energy requirements for heating follows about the same change as the effect of the reduction of the U value between the four climatic zones and for a point of reference the values of climatic zone A. From the transaction from climatic zone A to B the changes in these parameters are minor with a percentage 0.0–8.2 %. From climatic zone A to Γ a difference is observed of 86.0–95.1 % and from climatic zone A to Δ 140.7–152.2 %.

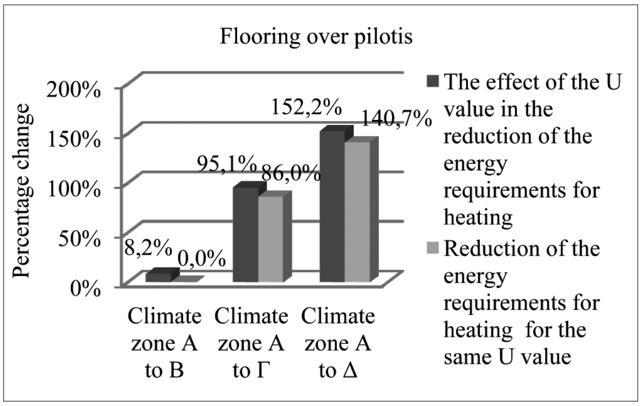

***Fig. 10.** The reduction of the U value and of the annual energy requirements for heating between the four climatic zones*

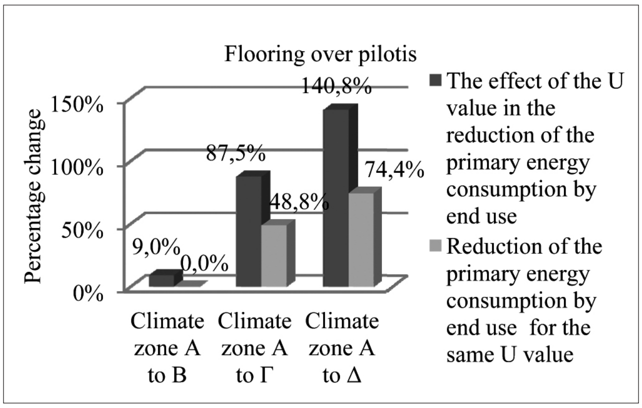

***Fig. 11.** Reduction of annual primary energy consumption for the change of U value of the vertical building elements for the four climatic zones*

Between the reduction in the primary energy consumption by end use and the effect of the U value a significant difference is observed in the percentage change (Fig. 11). The percentage change to the effect of the reduction of the U value from climatic zone A to B is 9.0 %, from zone A to Γ 87.5 % and from zone A to Δ 140.8 %. The average percentage change in the reduction of the primary energy consumption by end use from climatic zone A to B is 0.0 %, from zone A to Γ is 48.8 % and from zone Γ to Δ is 74.4 %.

3.3. Building element roof

The reduction of the U value (Fig. 12) in climatic zone A by 0.01 W/m^2.K leads to a reduction in the annual energy requirements for heating 0.190 kWh/m^2 and in climatic zone B 0.209 kWh/m^2.In climatic zones Γ and Δ the same change of the U value leads to a reduction of 0.373 kWh/m2 in zone Γ and 0.510 kWh/m^2 in zone Δ (table 5).

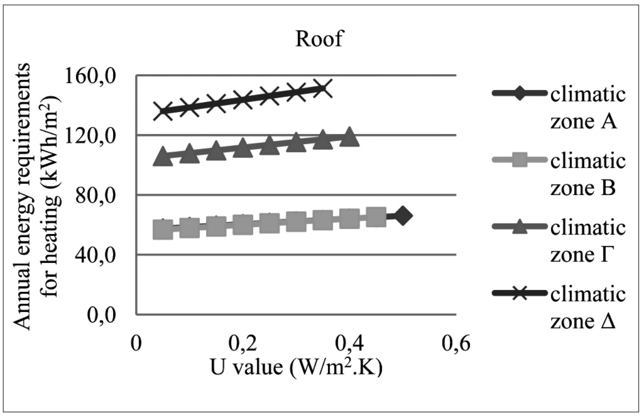

***Fig. 12.** The reduction of the U value and of the annual energy requirements for heating of the building element roof between the four climatic zones*

In the annual energy requirements for cooling (Fig. 13) a decrease 0.094 kWh/m^2 is observed in climatic zone A, in climatic zone B 0.082 kWh/m^2, in climatic zone Γ 0.046 kWh/m^2 and in climatic zone Δ 0.026 kWh/m^2 for a reduction of the U value by 0.01 W/m^2.K (table 5).

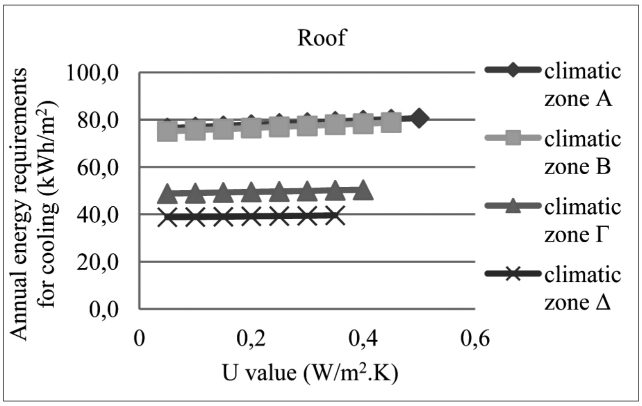

***Fig. 13.** Reduction of annual energy requirements for cooling for the change of U value of the building element roof for the four climatic zones*

The reduction of the U value in climatic zone A by 0.01 W/m^2.K leads to a reduction in the annual primary energy consumption by end use (Fig. 14) 0.300 kWh/m^2 and in climatic zone B 0.323 kWh/m^2. In climatic zones Γ and Δ the same change of the U value leads to a reduction of 0.508 kWh/m^2 in zone Γ and 0.671 kWh/m^2 in zone Δ (table 5).

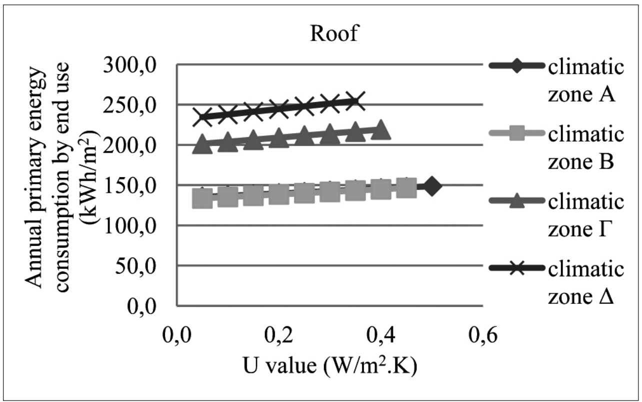

Fig. 14. *Reduction of annual primary energy consumption by end use for the change of U value of the building element roof for the four climatic zones*

Table 5. *Effect of the reduction of the U value by 0.01 W/m^2.K to the annual energy requirements for heating and cooling and the annual primary energy consumption by end use*

Roof inclined or flat	Reduction of U value 0.01 W/m^2.K			
	Climatic zone A	**Climatic zone B**	**Climatic zone Γ**	**Climatic zone Δ**
Annual primary energy consumption by end use (kWh/m^2)	-0.300	-0.323	-0.508	-0.671
Annual energy requirements for heating (kWh/m^2)	-0.190	-0.209	-0.373	-0.510
Annual energy requirements for cooling (kWh/m^2)	-0.094	-0.082	-0.046	-0.026

Evaluation

Between the reduction in the energy requirements for heating and the effect of the U value (Fig. 15) a significant difference is observed in the percentage change. The percentage change to the effect of the reduction of the U value from climatic zone A to B is 9.8 %, from zone A to Γ 96.2 % and from zone A to Δ 168.0 %. The average percentage change in the reduction of the energy requirements from climatic zone A to B is 0.0 %, from zone A to Γ is 84.9 % and from zone Γ to Δ is 137.9 %.

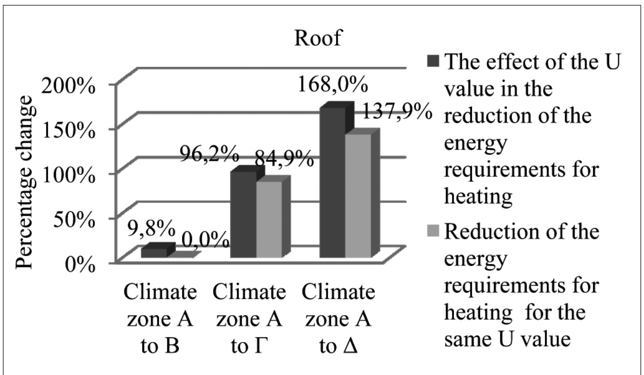

Fig. 15. *The reduction of the U value and of the annual energy requirements for heating between the four climatic zones*

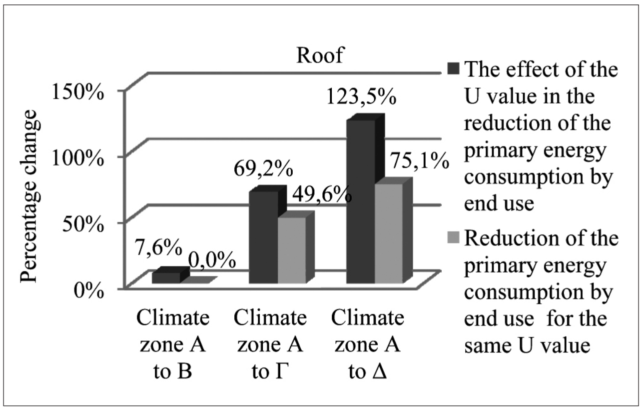

Fig. 16. *Reduction of annual primary energy consumption by end use for the change of U value of the building element roof for the four climatic zones*

Between the reduction in the primary energy consumption by end use and the effect of the U value a significant difference is observed in the percentage change (Fig. 16). The percentage change to the effect of the reduction of the U value from climatic zone A to B is 7.6 %, from zone A to Γ 69.2 % and from zone A to Δ 123.5 %. The average percentage change in the reduction of the primary energy consumption by end use from climatic zone A to B is 0.0 %, from zone A to Γ is 49.6 % and from zone Γ to Δ is 75.1 %.

4. Discussion

In the typical construction that was examined in this study the reduction of the U value appears to have significant influence in all the opaque building elements. The greater reduction in the energy requirements and primary energy consumption by end use is observed in the vertical building elements in all four climatic zones. This could be explained from the fact that they cover a significant percentage of the area of the building envelope. This reduction in the other building elements is about 50 % of the reduction of the vertical building elements.

The reduction increases during the transaction from climatic zone A to climatic zone Δ. Between climatic zones A and B the change in the reduction of the energy requirements for heating for the descending step of the U value is about 0.0–9.8 %. But in climatic zone Γ an increase 81.7–96.2 % and in climatic zone Δ 135.5–168.0 % is observed in all the opaque building elements of the building envelope.

In the primary energy consumption by end use the vertical building elements appears to have twice the reduction of the other building elements in all climatic zones. This reduction increases from climatic zone A to B about 7.6–9.0 %, from B to Γ 69.2–87.5 % and from Γ to Δ 123.5–140.8 % in all the building elements. This lower effect of the U value in the primary energy by end use could be explained by the influence of a number of other parameters to the final calculation of the primary energy such as the technical parameters of the heating and cooling system (efficiency ratio, EER, automation of HVAC systems etc.) and the indicators used for the calculation of the contribution of the form of energy source.

The effect of the U value in the change of energy requirements for cooling is about 90.0% lower than the energy requirements for heating and the primary energy consumption by end use. An increase or a decrease is observed depending on the building element and the climatic zone. From climatic zone Γ to Δ an increase is mainly observed however its importance is minor due to the from the fact that is lower up to 90.0% than the annual requirements for heating which overrides this difference and lead to a reduction of the annual primary energy consumption by end use. This increase could be explained from the fact that the reduction of the U value prevents outer temperatures, which are lower than climatic zones A and B, to be transferred in the internal of the building and reduce its temperature.

A reduction of the U value of 60% from the maximum U value of all opaque building elements, in the typical construction of this study, leads to reduction 29.2% in the annual primary energy consumption by end use in climatic zone A, in climatic zone B 27.9%, in zone Γ 27.9% and in climatic zone Δ 27.5%.

5. Conclusions

The reduction of the U value of the opaque building elements of the building envelope is a first approach for the energy upgrading of buildings and a step closer to the buildings with nearly zero energy consumption. In all climatic zones the reduction of the U value leads to a significant reduction in the primary energy consumption by end use and in the energy requirements for heating. With the reduction of their U value a significant reduction to the energy requirements for heating is observed, with an increase from climatic zone A to Δ between 137,9% and 173,2%, depending on the building element. The same trend is observed in primary energy consumption by end use with an increase from climatic zone A to Δ between 74,4% and 85,8%. The reduction of the energy requirements for cooling seems to be minor in relation to the energy requirements for heating and the primary energy consumption. These reductions could lead up to 30% lower energy consumption in residential buildings as a result of this study. However there is a distance from the final goal of the nearly zero energy building as the increase of the thickness of the insulating material should be considered in a cost optimal way. As a result other interventions and approaches could be considered, such as the effect of thermal transmittance of the windows of residential buildings in the energy consumption and the air tightness of the building. Windows with energy effective materials or increased number of window glazing could also be considered. Furthermore the upgrading of the efficiency of the HVAC systems and their automations would probably lead to a reduction of the energy consumption. Another approach that could be considered in this evaluation is the use of photovoltaic systems for the reduction of the energy consumption or other renewable energy sources and the use of solar panels for the reduction of the energy requirements for hot water.

On the way to meet the requirements of the nearly zero energy building only a combination of solutions, in a cost optimal way, would give the expected result.

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