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U-Value: A Key Role Parameter for Sustainable Buildings

Effrosyni Giama*, Elli Kyriaki, Agis M. Papadopoulos

Process Equipment Design Laboratory, School of Mechanical Engineering, Aristotle University of Thessaloniki, Building D, 54124, Thessaloniki, Greece

*Corresponding author: fgiama@auth.gr



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Buildings have a considerable environmental impact that corresponds to almost 30% of the global carbon footprint, with a prediction for further growth, and to 40% of the final energy consumption in the EU. The EU therefore has set a goal to reduce primary energy use by 20% by 2020, which is one of the five headline targets of the European 2020 Strategy. Moreover, the European Commission has established since 2002 a common policy for sustainable buildings and low environmental impact materials promoting energy efficiency and reduction of greenhouse gases (GHGs), based on a series of directives and regulations. A key role parameter for sustainable building construction is the appropriate building envelope's thermal insulation in order to reduce its thermal losses. This was firstly introduced in Greece with the Regulation of Building Insulation in 1979. Therefore, the paper focuses on the implementation of thermal insulation at buildings in compliance with the Greek national legislation framework during the last forty years. In this line of approach, measurements of the U-values and of the internal and external surface temperatures were carried out, in residential and office buildings. The sample consisted of buildings with construction dates that mirrored the development in legislation and in the building practice.

KEYWORDS: energy efficiency, sustainable building, thermal insulation, U-Value

Introduction

It is well known and documented that the building sector is responsible for the 40% of the total final energy consumed in the EU. Specifically, the residential sector was responsible for the 27% of the total final energy consumption in 2010, while the tertiary sector was responsible for the 16% respectively. Therefore, the European Parliament approved the Energy Performance of Buildings Directive (EPBD) 2002/91/EC and the recast Directive 2010/31/EC. Except from those Directives, the EU set the main goals for energy, transport and GHG emissions not only for 2020, but also for the following decades; 2030 and 2050. The main goal is no other than the gradual reduction of the energy consumption and GHG emissions (EEA 2015, Antoniadou et. al. 2015).

On a global scale, building sector accounts for the 32% (118,6 EJ) of final energy consumption for 2012 and 53% of global electricity consumption. According to the International Energy Agency (IEA), final energy consumption in building sector was increased by 1,5% every year, in 2000-2012. It is estimated that building's energy consumption will continue to have an increasing trend with a high rate (annually 1,4%), reaching 142,7 EJ (IEA 2015, Santamouris et. al. 2015)

Buildings can be divided in to two main categories: a) residential buildings and b) non-residential buildings. In Europe, 75% of building stock are residential buildings and only 25% are non-residen-



tial. More particularly, in Greece residential buildings can be divided in to two main subcategories: a) single-family houses and b) multi-family houses, as it is shown in Fig. 1.

The common goal is the reduction of energy consumption in buildings at least up to 20% and in

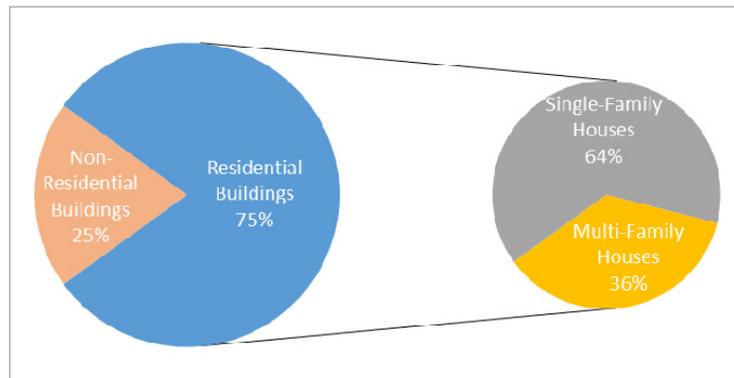


Fig. 1

Distribution of building sector in Europe and Greece

order to achieve this target, effective interventions in existing buildings are required. This need of improvement was initially expressed by means of the Directive 2002/91/EC for the Energy Performance of Buildings and its review (2010/31/EC). These Directives have been harmonized in Greek legislation with the following Laws and Ministerial Decisions (MD): (i) Law 3661/2008, (ii) MD 2008 for public buildings, (iii) Law 4122/2013 for under construction, respectively. Despite the fact that the Greek Law 4122/2013 has been published recently, the construction of the buildings is still following the demands of the previous regulation (Greek Law 3661/2008). KENAK (the Regulation on the Energy Performance of Buildings) along with TOTEE (the Technical Guidelines of the Technical Chamber of Greece) are leading in changing the way in building envelope upgrades (Antoniadou et.al. 2014, EURIMA 2011). In case of Greece and according to Hellenic Statistical Authority (Fig. 2), 41% of the existing building stock was constructed before 1970 under no regulation concerning insulation. Also, approximately 35% of the buildings were constructed in 1980-2010 under the 1st Thermal Insulation Regulation of Greece and only a small number of buildings (7%) were constructed after 2010 and are in accordance to the KENAK regulation (Hellenic Statistical Authority 2015, Theodoridou et. al. 2011).

It is of interest to notice, that the 1st Thermal Insulation Regulation was pretty strict for its time, as it can be seen compared to the respective German regulation in Table 1. In fairness it has to be added that the Greek regulation relied heavily on the German one, which preceded it by two years. The Greek regulation divided the country into three different climatic zones, base on the heating requirement, with different U-value requirements applying for each zone. The values presented in Table 1 are for zone B, which is Central Greece including Athens.



Fig. 2

Development of construction rate in Greece in accordance to Hellenic Statistical Authority

Table 1

The initial regulatory approach of the U values in Greece and Germany

Building element	Maximum U-value [W/m ² K]	
	German 1.Regulation (1.WSVO 1977)	Greek 1.Regulation* (TIR, 1979)
Walls including openings	1,45	1,90
Walls	0,6	0,7
Roofs	0,45	0,5
Floors to unheated rooms	0,80	1,9

The current Greek regulation (KENAK) which was issued in 2010, divides the country into four different climatic zones, based again on the heating requirements, as expressed by the Heating Degree Days. By comparing the maximum U values of Tables 1 and 2, it becomes obvious that KENAK has introduced reasonably strict U-value limits, which are in harmony with most contemporary European regulations. Furthermore, it is worth mentioning that in accordance to KENAK (and of course to the Energy Performance of Buildings Directive) all buildings, newly constructed or deeply renovated, public or private, need to obtain an Energy Performance Certification (EPC). According to the Ministry of Reconstruction of Production, Environment & Energy over 590 thousand certifications have been issued in the period of 2011–2014.

Table 2

Current U-value requirements per building element (KENAK)

Building element	Maximum U-value [W/m ² K]			
	Climate Zone			
	A	B	C	D
Roofs	0,50	0,45	0,40	0,35
Walls	0,60	0,50	0,45	0,40
Pilotis	0,50	0,45	0,40	0,35
Floors on the ground or above unheated spaces	1,20	0,90	0,75	0,70
Walls in contact with ground or unheated spaces	1,50	1,00	0,80	0,70
Windows	3,20	3,00	2,80	2,60
Facades	2,20	2,00	1,80	1,80

Methodology and measurements

The thermal transmittance, which is expressed by the heat transfer coefficient (U-value) is the most important feature, which characterizes the thermal performance of building elements. It expresses the rate of heat transfer through a structure, which can be a single material or a composite building element, divided by the temperature difference across that structure. It is therefore a measure of how much heat is lost through a given thickness of a particular material, including the three major ways in which heat transfer occurs – conductivity, convection and radiation. The units of measurement are W/m²K. Three temperature values are needed to calculate U coefficient. These three temperature values are the external and internal surface temperatures as well as the ambient air temperature.

The ambient temperatures, inside and outside the building, play an important role when calculating the U-value of an element. If one imagines the inside surface of a 1 m² section of an external wall of a heated building in a cold climate, heat is flowing into this section by radiation from all parts of the inside the building and by convection from the air inside the building. So, additional thermal resistances should be taken into account associated with inside and outside surfaces of each element. These resistances are referred to as R_{si} and R_{so} respectively with typical values of 0.12 Km²/W and 0.06 Km²/W for the internal and external surfaces, respectively (Giama and Papadopoulos 2012).

This is calculated by taking into consideration the reciprocal of the R-Value and then adding convection and radiation heat losses, as follows (Green Teg 2015),

$$U = \frac{1}{R} + \text{Convection and Radiation Heat Losses}$$

Within the framework of this paper, measurements of the U-value for the two main vertical building elements, namely brick-walls and concrete elements, were carried out. In total, 52 buildings in Thessaloniki, Greece, were measured, 26 residential and 26 office buildings. Based on the construction year, the buildings studied can be classified as depicted in Fig. 3.

The measurements were made using the device TM 200 U. U coefficient value is the most important parameter for the evaluation of thermal features of construction elements. To calculate U-value, four conditions must be respected:

- _ The outside temperature should be low,
- _ The room should be heated
- _ The wall should not be exposed to wind and sun
- _ The temperature difference between outside and inside temperature should be more than 20°C.

Once these four conditions are respected, the measurement of the three temperatures (T_i : inside temperature of the room, T_e : outside temperature, T_s : temperature of the internal surface of the wall) allows to get the U coefficient:

$$U = \frac{T_i - T_s}{0.125 * (T_i - T_e)}$$

The coefficient 0,125 corresponds to the superficial thermal resistance of the air-brush on the internal surface of the wall) (User Manual Umeter).

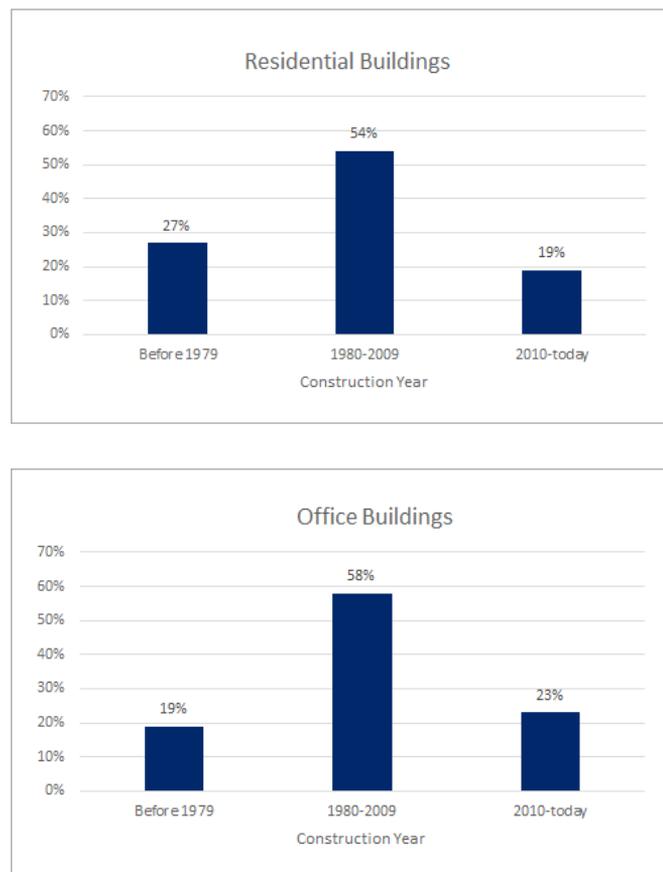


Fig. 3

Distribution of measured buildings based on the construction year

Results

The results carried out from the analysis of the measurements are presented below. The first statistical analysis depicts the relevance of U values in different constructing time periods according to the insulation regulation that prevailed when the buildings, both residential and non-residential ones, were constructed. More specifically, in Fig. 4 and Fig. 5, are depicted the results for residential and non-residential buildings respectively, constructed before 1979, that is prior to the introduction of the first Thermal Insulation Regulation.

It is obvious that U-values in the buildings constructed before 1979, when there was no requirement for thermal insulation, are really high. Moreover, it is observed that, reinforced concrete and brick walls have different properties: The brick walls was proved to have increased insulation capability compared to reinforced concrete and as a result brick's U-value for all cases is lower than reinforced concrete's. Still, given the lack of insulation, the overall difference is not really dramatic.

Fig. 4

U-value measured for residential buildings constructed before 1979

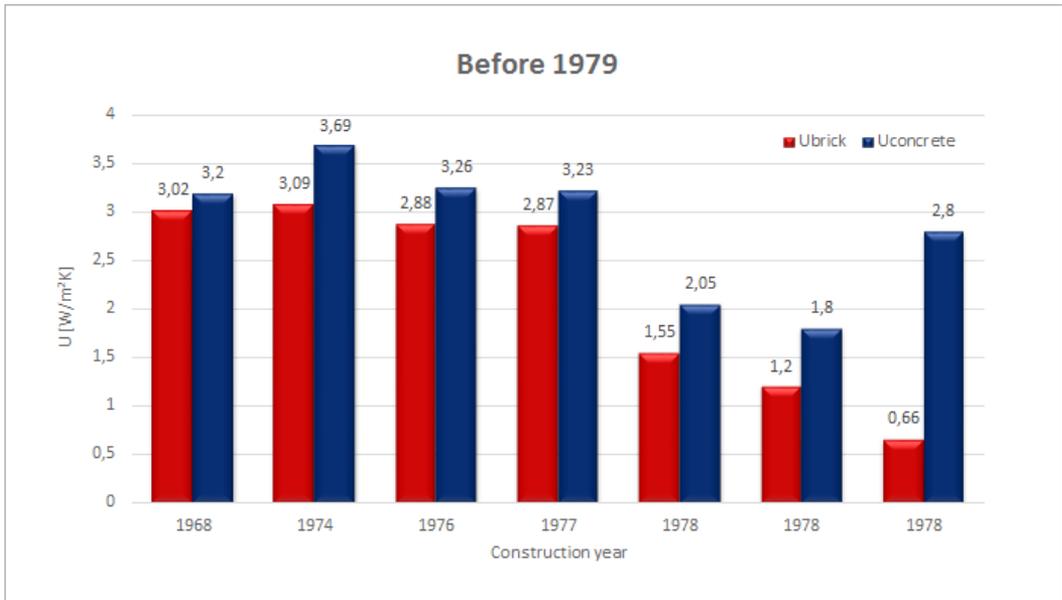
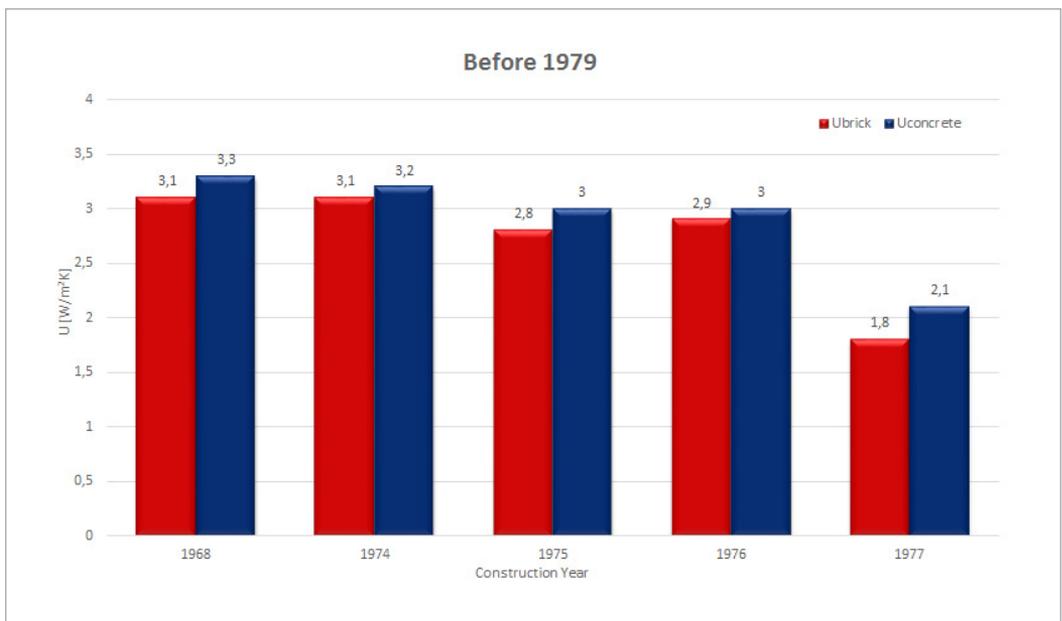


Fig. 5

U-value measured for office buildings constructed before 1979



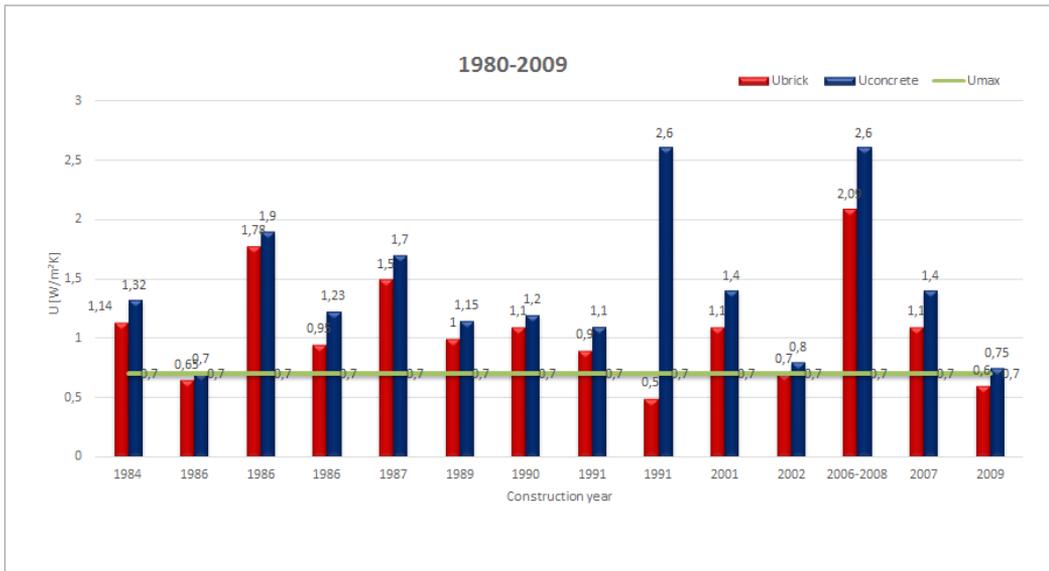


Fig. 6

U-value measured for residential buildings constructed in 1980-2009

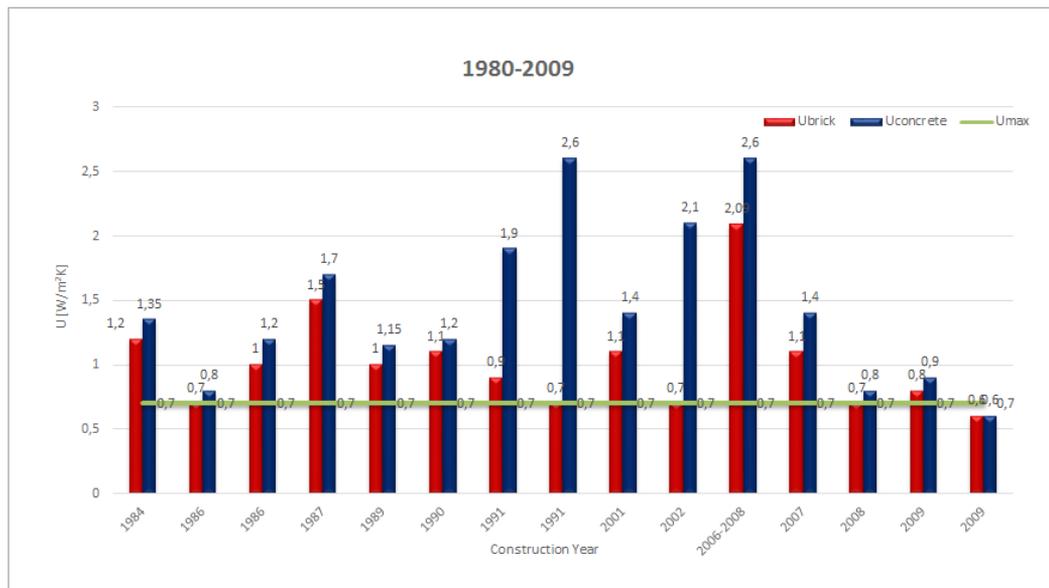


Fig. 7

U-value measured for office buildings constructed in 1980-2009

It is of interest to notice in office buildings, that although the brick elements present lower U-values, those are not that low as one would expect them to be, based on the much better thermal transmissivity value of clay bricks compared to armed concrete. This is mainly due to the fact, that the typical Greek office buildings of the 1960s and 1970s had rather thin brick walls, with thicknesses not exceeding 16 cm, thereby results in high U-values. One residential building constructed in 1978, with $U_{\text{brick}}=0,66 \text{ W/m}^2\text{K}$ and $U_{\text{concrete}}=2,8 \text{ W/m}^2\text{K}$, is worth noting. Brick's U-value, is quite low. This was due the fact that at this construction thermal insulating bricks were used, leading hence to a very good U-value. Then, in Fig. 6 and in Fig. 7, U-values for residential and non-residential buildings constructed in 1980-2009, are depicted. In this period, the Greek Thermal Insulation Regulation was in effect, which foresaw maximum U-values of $0,7 \text{ W/m}^2\text{K}$ for climate zone C.

From Fig. 7 and 8 it becomes clear, as the Thermal Insulation Regulation was not fully implemented. U-values, both for brick and reinforced concrete elements. The U values achieved are definitely im-

proved compared to those of older buildings. However, in most cases, the U-values measured were quite above the maximum U-values required by the Regulation, which indicates that insulation applied was not sufficient. Also, especially in office buildings, it was observed that in some cases, whilst brick walls were insulated, the load bearing elements of reinforced concrete were not. So, from fig. 9 and 10 and the U-values revealed for both brick and reinforced concrete elements, it becomes clear that the Thermal Insulation Regulation was not fully implemented.

Finally, in Fig. 9, 10, and 11 are depicted the results for the buildings constructed after 2010. The sample of buildings for this period is small, and this is absolutely representative of the economic recession that troubles Greece since 2009. One has to notice, that the number of construction per-

Fig. 8

Deviation between U_{max} and real Uvalue in residential buildings constructed between 1980 and 2009

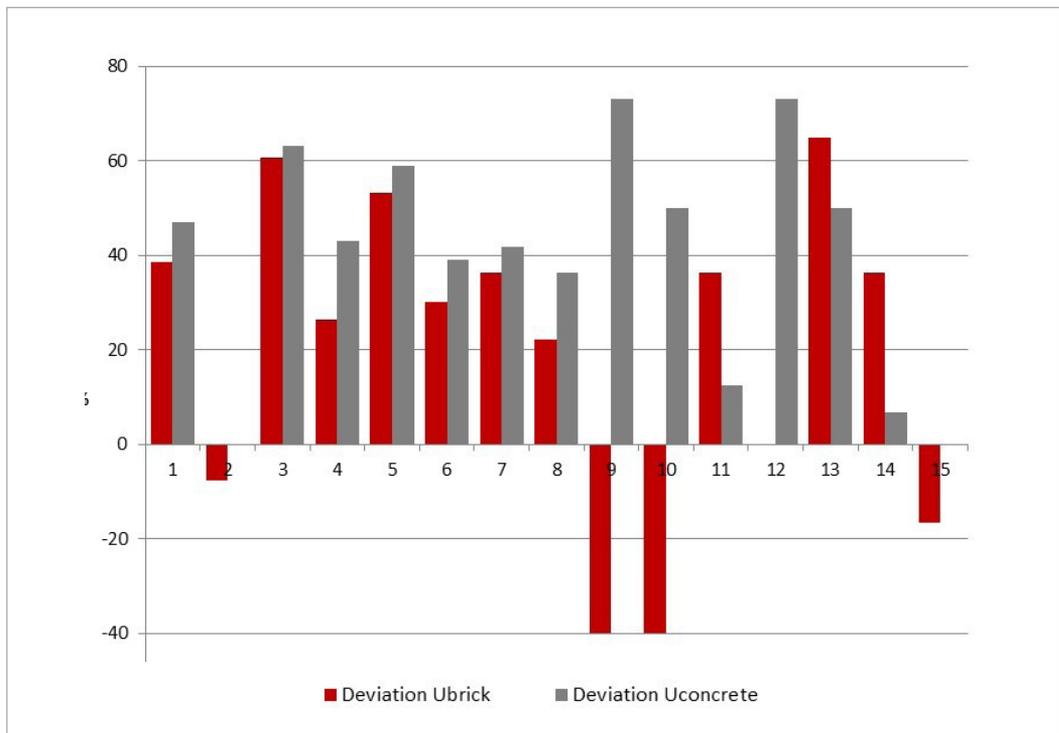


Fig. 9

U-value measured for residential buildings constructed after 2009



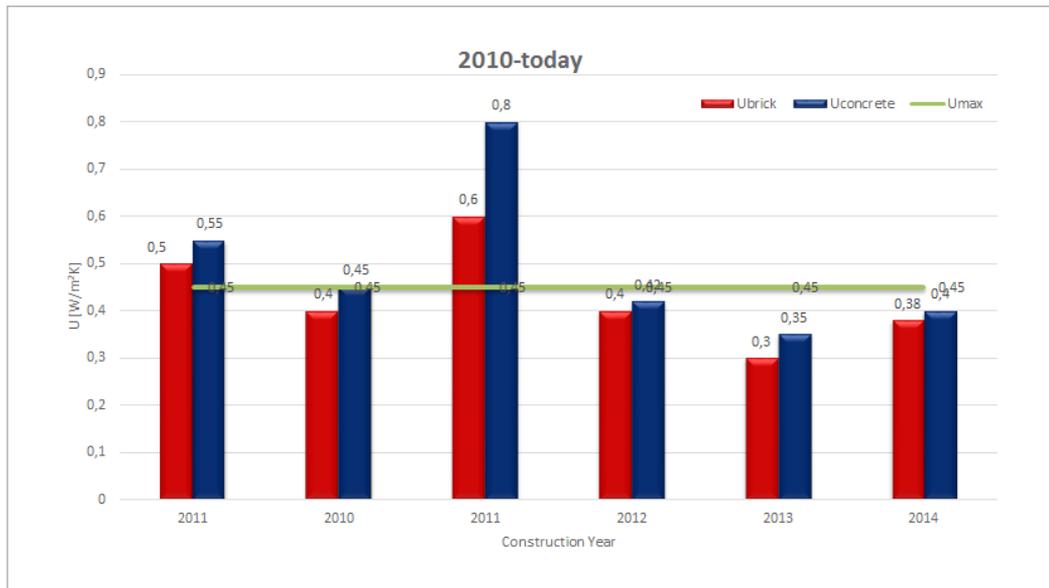


Fig. 10

U-value measured for office buildings constructed after 2010

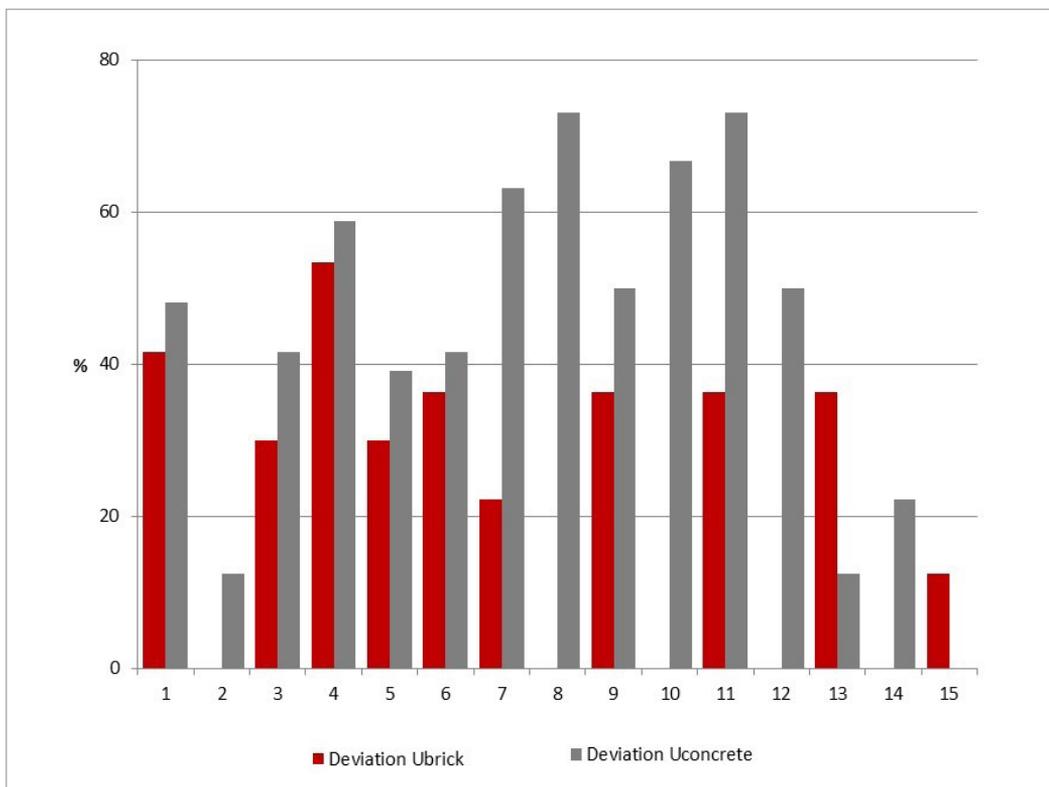


Fig. 11

Deviation between Umax and real Uvalue in office buildings constructed between 1980 and 2010

mits in 2014 was 13.100, compared to more than 77.400 in 2007 (Hellenic Statistical Authority 2015). After 2010, with the implementation of KENAK, thermal insulation requirements became significantly tighter. When looking at the results in fig. 10 and 11 one has to be careful, as the U-values measured, which are significantly above the ones foreseen by the regulation.

A careful research on those buildings showed that their building permits were issued before 2010, and hence prior to the introduction of KENAK. They therefore did not have to comply with the new

regulation. On the other hand, it is particularly hopeful, that the two residential and three office buildings constructed after 2012, comply fully with the KENAK requirements.

Lastly, the average U-value for the different time periods, is shown in Fig. 12, 13 and 14 for residential and non-residential buildings respectively. Overall, it is obvious that the thermal insulation of both residential and non-residential buildings' envelopes improved gradually, complying with the requirements of the regulations, albeit with a certain lag, both in terms of time of implementation and of U-values achieved.

The building envelope is also strongly connected with the constructions materials selection. The construction materials should be studied not only based on their technical efficiency and suitability but also according to their environmental impact. Based on Life Cycle Analysis methodology dominant construction materials such as concrete, brick, steel and insulation materials such as

Fig. 12

Average U-values for residential buildings

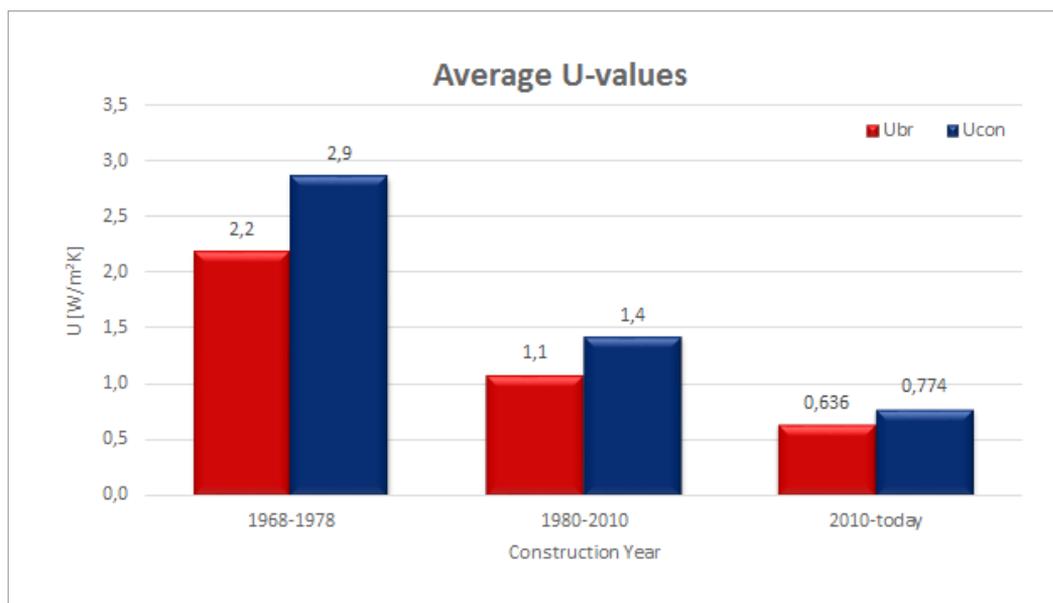
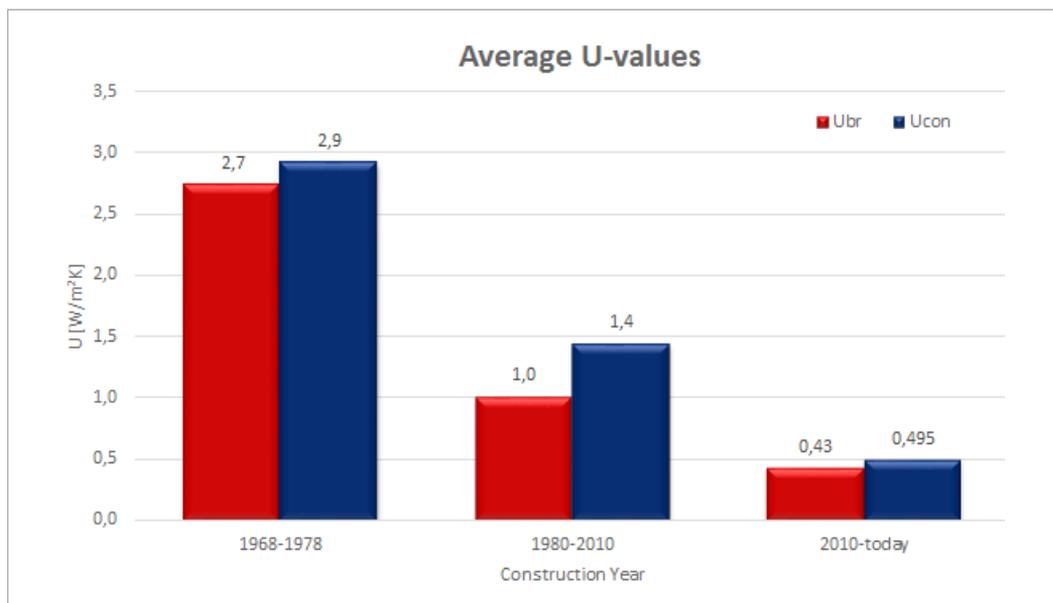


Fig. 13

Average U-values for office buildings



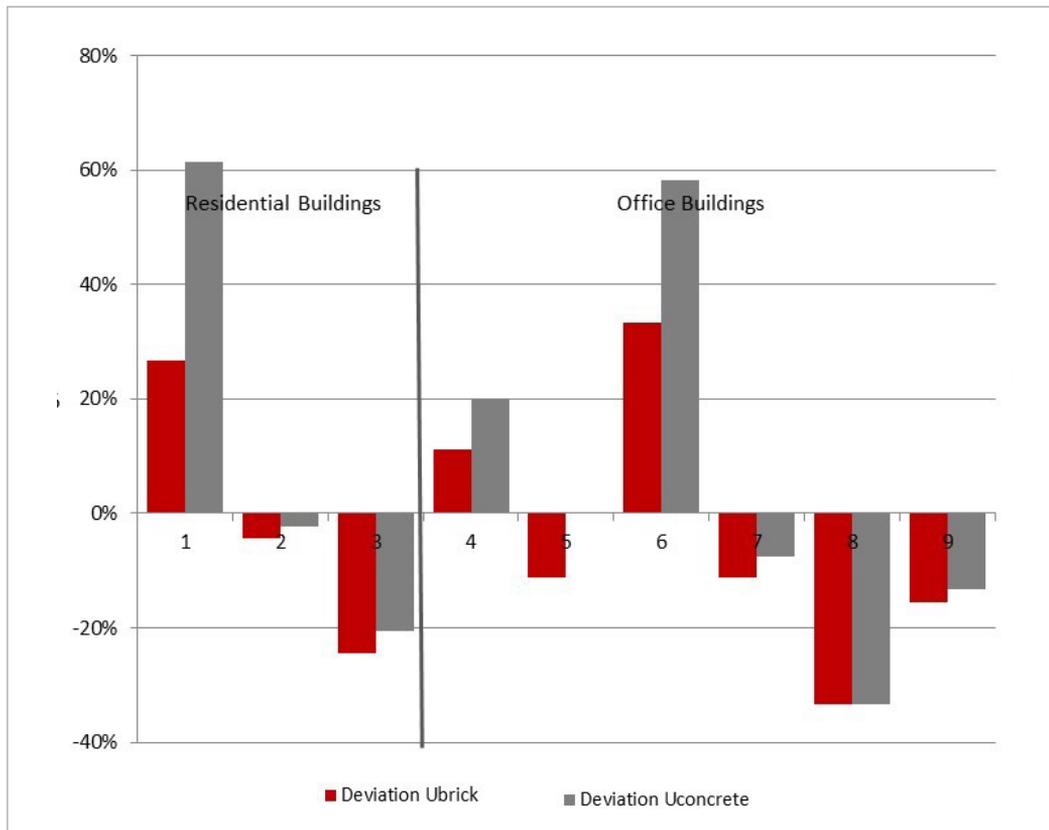


Fig. 14

Deviation between U_{max} and real U -values in contemporary buildings constructed after 2010

stonewool, extruded and expanded polystyrene have been evaluated (Bribian et.al., 2011; Cabeza et.al., 2014; Giama and Panadopoulos, 2015; Bikas and Chastas, 2015). The evaluation results have shown that production procedures as well as the transportation process contribute mainly to air emissions and more specific to CO_2 production. Actually the CO_2 is the most significant emission as a quantity to all the construction products studied. Focusing mainly on insulation materials, the cradle-to-gate environmental evaluation results showed that expanded polystyrene and stonewool have lower contribution to environmental impact categories studied compared to extruded polystyrene and polyurethane foam. The functional unit used to the studies mentioned was for the 1kg of insulation material produced. In case the functional unit is changed to the mass of insulation material needed for insulating $1m^2$ of surface taking into consideration the thermal resistance R of the building element the results are slightly different. In that case expanded polystyrene, extruded polystyrene and stonewool have lower contribution to environmental impact categories studied compared to polyurethane foam. Considering those results, it becomes evident, that there is significant potential for improving the current by reducing the environmental impact of the basic building materials and improve the environmental rating of buildings (Garcia et.al., 2015). Considering that production is the key process and that the use of energy and raw materials are the main issues to deal with, one could think of measures focusing on [20]:

- _ the use of renewable energy sources for the energy needed at the production process, either on site, like for instance biomass, or off-site, like green electricity
- _ the end-of-life management of building materials and the calculation of waste flows at the production processes, including the reuse, recovery and recycling potential,
- _ the upgrading of the industrial infrastructure (refurbishment, improved monitoring and con-

trol of energy consumption, implementation of Energy Management Systems such as ISO 50001),

- reducing the transportation emissions by preferring locally extracted raw materials and also fostering the use of biofuels for the vehicles.

Finally, reuse and recycling of building materials is essential in order to reduce the embodied energy in buildings; the use of recycled steel and aluminium could lead to savings of more than 50% in building's embodied energy. An even more drastic step is to promote the reuse of construction materials and gain extra points on the evaluation procedure of green certification schemes.

Conclusions

The necessity for improving the buildings' energy efficiency is expressed by a variety of legislative measures in Europe and worldwide. This improvement cannot be considered as an independent phenomenon, but has to be seen in context with the environmental and energy policies that have become part of the European and international agenda. Furthermore, this development has strong economic and social consequences, as it affects the comfort and well-being of millions of households. Producing a piece of legislation is one thing, implementing it is, sometimes, another. In order to determine this possible difference, a field study was carried out by the Process Equipment Design Laboratory at the School of Mechanical Engineering of the Aristotle University of Thessaloniki. In this paper the results of measuring the U values in 52 buildings located in Thessaloniki, Greece, of which 26 residential and 26 office, are presented. The results were grouped based on the construction year of the buildings, in compliance with the national regulations valid in the period of the construction. It was observed that, before 1979, a time where thermal insulation regulations did not exist, buildings were built without insulation resulting in significant heat losses. All buildings had similar thermal transmittance properties. Later on, with the implementation of the first Greek Thermal Insulation Regulation, things began to improve. In the beginning, it was applied partially, mainly in the masonry, which had the form of the double brick wall with the insulation in the cavity in between. However, the reinforced concrete elements were frequently left uninsulated, especially in office buildings. The fact that the measurements showed the majority of buildings of this period, failed to meet the requirements foreseen by the regulation, came as a confirmation of this practice. Still, the measurements also showed that the implementation of the regulations gradually improved. In that sense, it is encouraging to notice that, despite the depressing situation of the Greek construction sector, which has suffered a contraction of almost 70% between 2009 and 2016, the tight requirements of the new regulation, introduced in 2010, seems to be achieved in practice. External thermal insulation composite systems have succeeded the double brick wall construction, reducing also thermal bridges, high quality insulation materials are used and quality of craftsmanship has improved by means of training. The fact that the final consumers have become more sensitive to energy efficiency, as oil and gas taxation has been increased by 60% in the same period, is certainly also a factor not to be neglected.

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EFFROSYNI GIAMA

Laboratory Teaching Staff, Dr. Mechanical Engineer MSc

Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki

Address

Process Equipment Design Laboratory, School of Mechanical Engineering, Aristotle University of Thessaloniki, Building D, 54124, Thessaloniki, Greece
Tel. 0030 2310 996153
E-mail: fgiama@auth.gr

ELLI KYRIAKI

PhD Candidate, Mechanical Engineer

Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki

Address

Process Equipment Design Laboratory, School of Mechanical Engineering, Aristotle University of Thessaloniki, Building D, 54124, Thessaloniki, Greece
Tel. 0030 2310 996087
E-mail: kelli@auth.gr

AGIS M. PAPADOPOULOS

Professor

Mechanical Engineering Department,

Director

Process Equipment Design Laboratory

Vice-Chairman

Governing Board, Open University of Cyprus

Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki

Address

Process Equipment Design Laboratory, School of Mechanical Engineering, Aristotle University of Thessaloniki, Building D, 54124, Thessaloniki, Greece
Tel. 0030 2310 996015
E-mail: agis@eng.auth.gr

About the authors