A tool to facilitate energy retrofitting policies for urban residencies in Greece

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Key words: spatial planning, real estate development, land management, urban renewal, energy policy, energy & carbon savings, young surveyor.

SUMMARY

This paper presents a tool created to support municipal energy saving policies; in particular the tool is used to map energy consumption of the residential building stock and visualise and evaluate various retrofitting interventions. Firstly, a database of the retrofit characteristics of the housing stock of the area is created by using statistical data and primary data derived from field surveys. This database is further extended with data about energy consumption and energy class, which are derived from simulations of the typologies of residencies in the area and these are extrapolated to the entire stock. Then, a review of existing energy retrofit policies and current trends in improving housing energy efficiency is conducted, leading to the identification of the most relevant retrofit options. These options are then evaluated to assess (a) which intervention is the most effective in massive reduction of energy use and carbon emissions, and (b) which one is most economically attractive to each individual house owner. An adaptation and application of the methodology to the Greek urban environment of Kos island, shows that envelope insulation is the most effective intervention across the city, but installing solar thermal collectors for domestic hot water produces the greatest energy and carbon cuts for the individual house owner. The policy implications of the findings of the study are discussed.

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1. INTRODUCTION

Current studies show that European cities consume 70% of the overall primary energy consumption of the continent, expected to reach 75% by 2030. The building stock account for the 40% of final energy consumption and 63% of that is consumed within the residential sector (European Institute for Energy Research, 2012a, 2012b). The Energy Performance Buildings Directive (EPBD 2002/91/EC as modified by 2010/31/EC) is adopted by the EU countries and more recently the Directive 2012/27/EU requires from each member the establishment of a long term strategy for investment in "green" interventions and improvements to the existing building stock in order to reduce energy use and greenhouse gas emissions.

This paper addresses the problem of energy consumption of the dwelling stock in the urban environment, using GIS to map energy consumption and calculate the energy and CO_2 emissions savings after certain retrofitting interventions. The overall aim of the project is to provide a tool to facilitate location-based methodology for evaluating various retrofitting interventions; and to support decision making in the context of location-based policy implementation in order to promote effective, sustainable urban planning.

The case study is focused on the urban centre of Kos Island, in Greece. The residential building stock of the area is analysed in terms of energy consumption and the potential savings for various retrofitting measures are calculated.

Objectives:

- Build a database with information on buildings characteristics, households and dwellings characteristics and energy performance;
- Create a building typology of the area by identifying the most representative building types for the different eras;
- Calculate energy consumption, assess energy performance and classify the stock according to their characteristics;
- Propose retrofitting measures based on the current trends and existing situation; and
- Compare and contrast different interventions by calculating potential energy and CO2 savings.

2. LITERATURE REVIEW

The literature review is consisted of two parts. One has to do with the building stock models and how these are presented in recent research work. The other part has to do with the existing legislative framework, within which policies are formed, in Europe and in Greece.

2.1 The building stock models

Reviews on building stock models to assess energy consumption is published in recent research works and the distinction between top-down and bottom-up approaches is defined (Swan & Ugursal, 2009; Kavgiz et al. 2009).

Top-down models are macroeconomic methods that establish a relationship between the total energy consumption and the housing and economic data (Hirst, 1978; Bentzen & Engsted, 2001). On the other hand, bottom-up models consist of separate components, combined to measure their individual impact on energy consumption. Several authors have developed and applied bottom-up building stock models to European countries (Gouveia et al. 2013; Uihlein & Eder 2010).

Bottom-up models may be classified into statistical and engineering approaches. Statistical methods rely on historical data to identify relationships between energy end-use and total energy demand (Baker & Rylatt, 2008; Guerra Santin et al., 2009; Swan et al., 2011; Mastrucci et al., 2014;). The engineering approaches use data about the housing stock on a representative set of buildings with a numerical model to calculate energy consumption and attribute it to various end-uses. This method has been used in the work of Fracastoro & Serraino (2011) and Mata et al. (2013).

Geographical Information Systems have been employed in engineering modelling approaches at city level. Some examples are the projects of Heiple & Seilor (2008), Theodoridou et al. (2012) and Caputo et al. (2013). In the work of Dall'O' et al. (2012a, 2012b) GIS is used in the methodology for evaluating the energy performance of residential buildings and to evaluate retrofitting measures.

However, a GIS-platform, facilitating the energy policy making, should provide the capabilities of mapping energy consumption and emissions, evaluating the performance and assist in the energy performance certification and also assist in targeting specific areas in need. This holistic approach is what is proposed in this paper, with the use of statistical analysis and spatial analysis techniques to assist policy makers, land managers or energy planners in every aspect of their work, in a fast and effective way.

2.2 The legislative framework

The first legislative measure on the Energy Performance of Buildings in Europe is the Council Regulation (EC) 91/2002. More recently, the European Parliament voted for a revised directive on buildings energy performance, the Directive 2010/31/EC.

In Greece, the procedure of evaluating energy performance of buildings has changed through the years and has been adapted to the European standards. The main legislative framework, under which energy audits and retrofitting schemes take place in Greece, is seen shown in Table 1.

Table 1 – Legislative measures on buildings energy performance (1975-2005)

Year	Legislation
2008	N.3661/08 for the Energy Efficiency of Buildings. Harmonisation with the European Energy Performance of Buildings Directive 2002/91/EC (Gov. 89/A/2010)
2010	Revised "Regulations on Buildings Energy Performance" (KENAK) (Gov. 407/B/2010)

	Article 10 of Law N.3851/2010 “Accelerating the development of renewable energy sources to tackle the climate change” (Gov. 85/A/2010)
	Article 28 of Law N. 3889/2010 “Financing Environmental Interventions, Green Fund, Ratification of Forest Maps and other Provisions” (Gov. 182/A/2010)
2013	N.4122/13 Energy Efficiency of Buildings. Harmonisation with the European Parliament and Council Directive 2010/31/EU (Gov. 42/A/2013)

The procedure of energy audits is explained in the technical specifications issued by the Technical Chamber of Greece (

Table 2).

Table 2 – Technical specifications about the energy performance audits

Specification	Subject
TOTEE 20701-1/2010	Detailed national standards parameters for calculating the energy performance of buildings and for issuing the energy performance certificates
TOTEE 20701-2/2010	Thermo-physical properties of building materials and testing of thermal insulation adequacy of buildings
TOTEE 20701-3/2010	Climatic data of Greece
TOTEE 20701-4/2010	Instructions and forms for energy audits of buildings, boilers and heating and air-conditioning facilities

Buildings in Greece account for approximately 36% of the total energy consumption. The main reasons why Greek buildings consume so much energy are:

- Outdated technology of windows/doors (frames/single glazing);
- Lack of sun protection;
- Inadequate use of solar potential;
- Inadequate maintenance of heating / air-conditioning systems (Ministry of Environment, Energy and Climate Change, 2012).

Within this context, the Ministry of Environment, Energy and Climate Change of Greece (YPEKA) has launched the “Energy Efficiency at Household Buildings” program – a set of financial incentives to the owners to implement retrofitting measures in residential buildings, built before 1/1/1990 in regions where land value is less than 2.100 €/m^2. According to this programme three interventions are proposed for retrofitting in the residential sector.

- Intervention 1: Improvement of the building envelope - Roof and façade insulation

This intervention results in a great drop of total energy consumption. Assumptions are made for the type of insulation and the width of the insulation layers for the walls, floors and roofs.

The cost of this measure is estimated at 50€/m^2 for the walls, 40€/m^2 for the roofs και 20€/m^2 for the floors.

- Intervention 2: Use of solar thermal power for hot water provision

According to this scenario the energy consumed for hot water provision is entirely provided by a flat solar power collector, with 45^0 inclination, south orientation and capacity factor of 0.369. The area of each panel is calculated at 2.5 m^2 per dwelling and the cost of the intervention is estimated at 450€/m^2.

- Intervention 3: Windows replacement

The windows are replaced with new, double-glazed, aluminium framed that reduce the ventilation losses by 50%. The cost for this intervention is estimated at 280€/m^2.
These retrofitting interventions are simulated individually and are evaluated for their impact on energy consumption independently.

3. METHODOLOGY & CASE STUDY

The methodology is based on a bottom-up, engineering-based approach, with the use of representative residential building typologies, called archetypes (Caputo et al., 2013) and the TEE-KENAK – the official software launched by the Technical Chamber of Greece (TEE) for the assessment of the energy performance of buildings (C. Retsas, 2014). An overview of the methodology is shown in Figure 1.

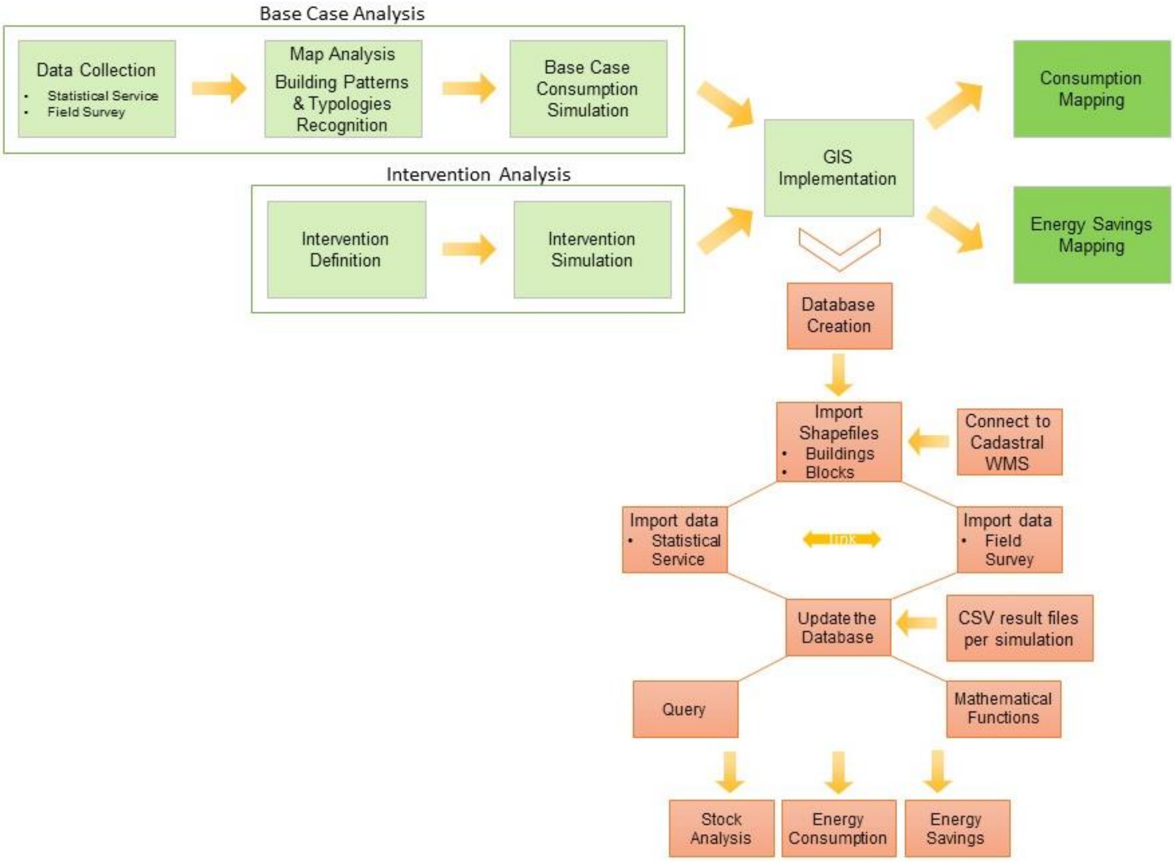

Figure 1 - Methodology flowchart

The necessary data collection for the case study includes:

a) Statistical data provided by the Hellenic National Statistical Authority (El. Stat.), including real and permanent population, number of households, exclusive, main and secondary use of buildings, number of floors, year of construction at a building block scale;
b) Climatic data for the particular study area, from the Hellenic National Meteorological Service.
c) Data concerning the residential building stock:
    a. General building data (location, year of construction, area, volume, floors, type);
    b. Building envelope (construction materials, type of roofing, transparent areas, openings, orientation, U-values, state of maintenance);
    c. Systems (technologies used for space heating, cooling and hot water provision).

The study area is the urban centre of Kos, Greece, on the South-eastern part of Europe, as seen in **Error! Reference source not found.**. The island belongs to climatic zone A, with 601-1100 heating degree days (HDD) (TOTEE, 2010). It consists of buildings of permanent dwellings with continuous occupancy throughout the year (**Error! Reference source not found.**, **Error! Reference source not found.**).

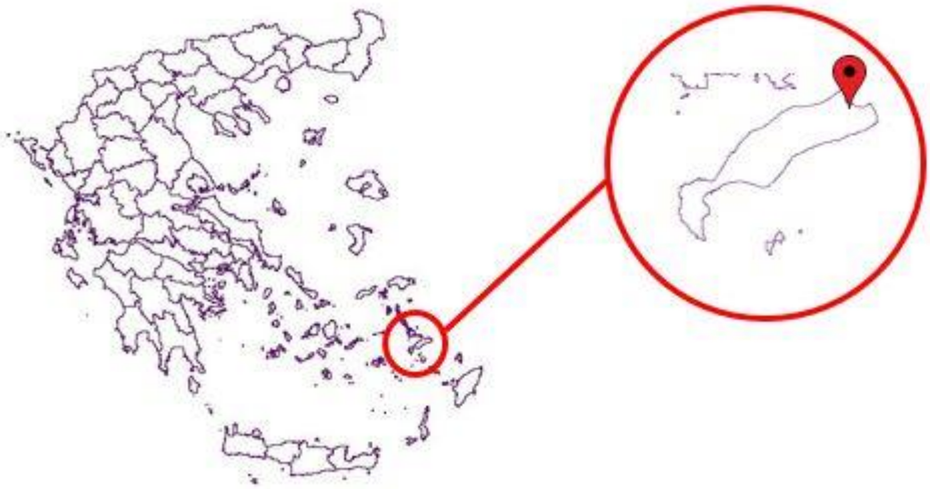

Figure 2 – The study area

Figure 3 - Typical examples of residential buildings in the area

A field survey took place in the area under study to collect the necessary data. The age of the building was estimated by the surveyor. The type of the roof was flat and made of concrete in all the cases in the town of Kos. Information about the number and type of windows was collected by external on-site observation of the buildingsA qualitative classification of the original construction and maintenance of the building was recorded too, in the scale of good – moderate – bad.

For the heating systems the use of oil has been the usual practice in every type of house in the region, at least until the economic crisis of 2008. For space cooling the number of cooling units was recorded according to the number of the external units observed around the house. Domestic hot water was assumed that is provided by local units, using electricity, apart from the cases that solar thermal collectors were observed on the roofs, either during the field survey or by observing aerial photographs of the area. The width of the road and neighbouring buildings were also recorded, in order to calculate the shadings.

The representative building archetypes are defined according to the harmonised structure for European building typologies (TABULA) for residential buildings and the work of Daskalaki et al. (2011), concentrated on the Hellenic building stock, adapted to the characteristics of the study area, according to the usual building practices.

Table 3 shows the allocation of the residential buildings of the area to the defined typologies.Almost 57% out of total 1836 residential buildings of the existing stock belong to class B. This construction period is characterised by the use of reinforced concrete and the prevalence of multi-family buildings. Till 1980, thermal insulation was not part of the usual building practice. Thermal insulation to new buildings was introduced in the building code in 1979 and is implemented since 1981 (Theodoridou et al., 2011). The majority of class D buildings have double-glazed windows, 76% of them make use of solar thermal power for hot water provision and are not eligible for the “Energy Efficiency at Household Buildings” program.

Table 3 - Classification of buildings in the study area (source: El. Stat.)

Classification	**Construction period**	**Percentage of buildings per age group**

Class A	1919-1945	9.15%
Class B	1946-1980	56.86%
Class C	1981-1990	25.33%
Class D	1991-2010	8.66%

For the needs of the energy consumption simulation, the geometrical characteristics of the buildings as well as the heating and DHW installations were assumed to be the same for every age class, as shown in **Error! Reference source not found.**. Real building examples per age class, with exact architectural, electrical and mechanical plans, would provide greater confidence in the results, but this would not serve the objective of a fast and cheap tool.

Table 4 - Building Archetypes

Age Class		**Archetypes**	**Description**
A	Single Family Houses (SFH) Typical height: 3.00m Number of floors: 1 Average area: 64m^2 No insulation	A1	No solar thermal collector Single-glazed, wooden frame windows
		A2	Solar thermal collector (2,5m^2/ residence) Single-glazed, wooden frame windows
		A3	No solar thermal collector Double-glazed, aluminium frame windows
		A4	Solar thermal collector Double-glazed, aluminium frame windows
B	Multi-family Houses (MFH) Typical height: 3.00m Number of floors: 2 Average area: 200 m^2 No insulation	B1	No solar thermal collector Single - glazed, aluminium frame windows
		B2	Solar thermal collector (2,5m^2/ residence) Single-glazed, aluminium frame windows
		B3	No solar thermal collectors Double-glazed, aluminium frame windows
		B4	Solar thermal collector (2,5m^2/ residence) Double-glazed, aluminium frame window
C	Multi-family Houses (MFH) Typical height: 3.00m Number of floors: 3 floors Average area: 300 m^2 Insulated	C1	No solar thermal collector Single - glazed, aluminium frame windows
		C2	No solar thermal collectors Double-glazed, aluminium frame windows
		C3	Solar thermal collector (2,5m^2/ residence) Single-glazed, aluminium frame windows
		C4	Solar thermal collector (2,5m^2/ residence) Double-glazed, aluminium frame window
D	Multi-family Houses (MFH)	D1	No solar thermal collectors Double-glazed, aluminium frame windows

	Typical height: 3.00m Number of floors: 3 floors Average area: 300 m^2 Insulated	D2	Solar thermal collector (2,5m^2/ residence) Double-glazed, aluminium frame window

El. Stat. provided the base map of the buildings of 2000, blocks and roads of the study area in shapefile format. The 2009 orthophotos provided by Web Mapping Service (WMS) of “Ktimatologio A.E.” - the Hellenic Cadastral Authority – was used as a data source to evaluate the completeness of the base map provided by El Stat and update it; newer building units that are not included in the El Stat base map were added.

14 simulations were executed to get typical primary energy consumption, consumption per end-use and the total CO_2 emissions per m^2. Certain parameters were used according to the technical specifications (TOTEE, 2010) in terms of:

a. The building envelope and
b. The electromechanical installations for heating, cooling and hot water provision.

For each archetype, the three interventions were tested on the software to give the new energy balance, class and CO_2 emissions. The calculated energy consumption though, is considered overestimated, as the simulation software uses an average operation time of 18 hours, which is not reflecting the reality. This is the case in many engineering, bottom – up models, as it is mentioned in Heiple & Sailor (2008). For that reason, a downscale of the results to a 12-hour operation was attempted to get more realistic values of energy consumption. For the classification of buildings and decision on the eligibility for the interventions though, the original values were used, as these are legally recognised by the planning authorities.
Visualisations of the energy consumption are created in ArcMap for every intervention. Maps of the classification of buildings according to their consumption and how this is changed with every intervention are created. The clustering of the results is also analysed, proving the connection between space and energy consumption.

4. RESULTS

For the base case scenario, the consumption of primary energy varies from 135.6 KWH/m^2 for the newest or already retrofitted building stock to 306.2 KWH/m^2 for the multifamily buildings built before 1980 that lack insulation, are bigger and harder to heat. The largest amount of energy goes to heating, which suggests great consumption of oil in the area.
The cooling needs last from June to end of August and are satisfied by air-conditioning units that are relatively new as they were installed after the construction of the building. The contribution of the cooling energy demand to the yearly consumption varies from 2.2% to 5.2%.
The archetypes that use solar collectors for DHW have great savings in electricity, whereas residences built after 1980 are better insulated and have reduced heating and cooling energy demand. CO_2 emissions vary from 36.6 kg/m^2 to 90.4kg/m^2 annually. Newer and recently renovated buildings have the lowest scores. The energy balance and energy class per archetype is summarised in Table 5.

Table 5 – Calculated quantities of the energy balance (KWh/m^2)

	Heating	**Cooling**	**DHW**	**Primary Energy Consumption**	**Energy Consumption Class**	**CO2 Emissions (Kg/m^2)**
A1	174.9	10.9	80.1	265.9	F	73
A2	174.9	10.9	14.5	200.9	E	51.8
A3	159	11.1	80.1	250.2	F	73
A4	159	11.1	19.9	190	E	48.8
B1	139.4	6.7	160.2	306.2	G	90.4
B2	139.4	6.7	54.9	200.9	E	54.4
B3	127.3	6.8	160.2	294.2	G	87.5
B4	127.3	6.8	54.9	189	E	51.6
C1	137	6.7	72.2	215.8	E	59.8
C2	107.6	7	72.2	186.8	E	52.8
C3	137	6.7	21.3	164.9	D	43.5
C4	107.2	7.1	21.3	135.6	C	36.6
D1	107.6	7	72.2	186.8	E	52.8
D2	107.2	7.1	21.3	135.6	C	36.6

The majority of the stock (44%) belongs to class G - the most energy-consuming class and 38% belongs to class E. Only 10% belongs to class C, which is the most energy-efficient class found in the study area.

There is great connection between the age of construction and the energy class. This has to do with the materials and technologies used and the valid legislation in every time period. But in terms of total primary energy consumption, the size of the building plays an important role. Therefore buildings of age group D, which are newer, better insulated and better equipped consume more as a result of their size.

Spatially, as shown in Figure 4, energy classes are distributed in space creating certain neighbourhoods with distinctive issues that could be specifically targeted. For example, the northern part as well as the central part of the study area is considered problematic, with many G-class buildings. This is the oldest stock of the area that needs retrofitting interventions to the building envelope and the electromechanical installations.

Figure 4 - Existing energy classes in the study area

4.1 Energy savings potential

The suggested interventions are assessed both individually and in connection to the whole study area. Individually, the intervention of adding a solar thermal collector for domestic hot water provides the best results for every archetype that is not already equipped with such technology. Especially for the archetypes A3, B1 and B3, intervention 2 provides up to 50% savings (Figure 5). As it is illustrated, not all the interventions are applicable to all the archetypes, depending on their characteristics.

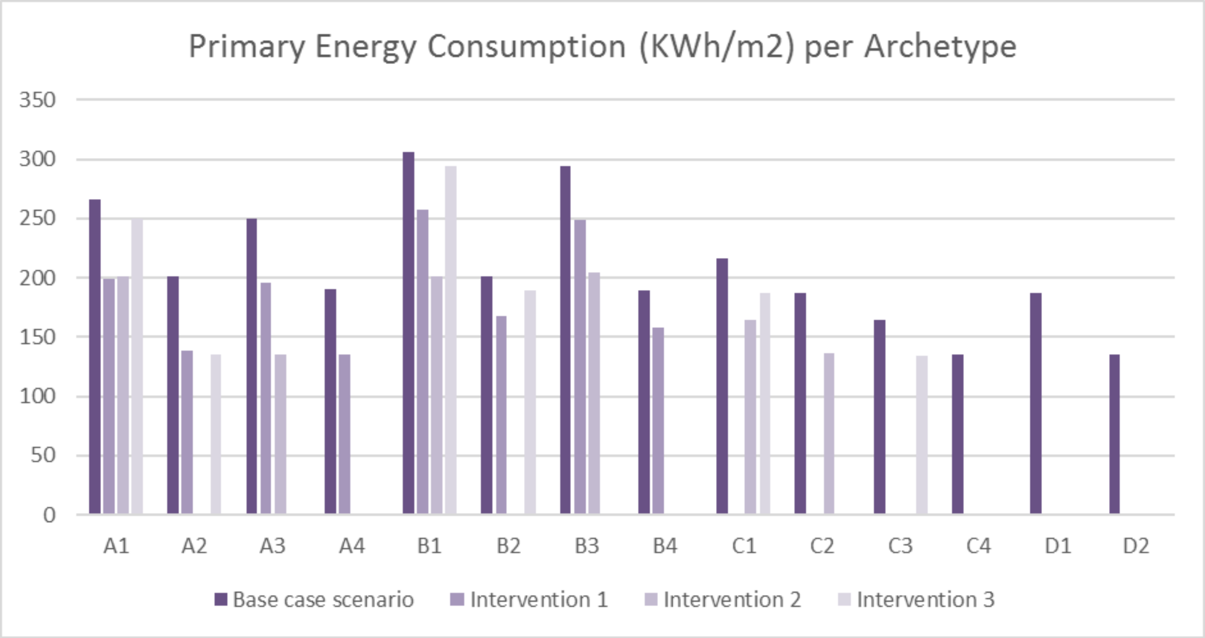

Figure 5 - Energy savings per intervention for each archetype

When the interventions are tested for their effect on total energy consumption, as a result of mass interventions in the area, intervention 1, is the most effective one. More specifically, intervention 1 results in 50% reduction of energy consumption in the study area, whereas interventions 2 and 3 result in reduction of 44% and 46% respectively.
On the other hand, intervention 2 provides the best results in energy savings (
Figure 6) and carbon emissions (
Figure 7) per residence and has a greater impact on the energy consumption classification of the stock; after implementing this intervention, the majority of the buildings improve their class by one or two rankings, bringing the entire stock between classes C and E. No buildings are then classified as F and G, a result which is not achievable with any of the other two interventions (Figure 8).

Figure 6 - Energy savings per residence after installing solar thermal collectors for DHW

Figure 7- Carbon emissions savings per residence after installing solar thermal collectors for DHW

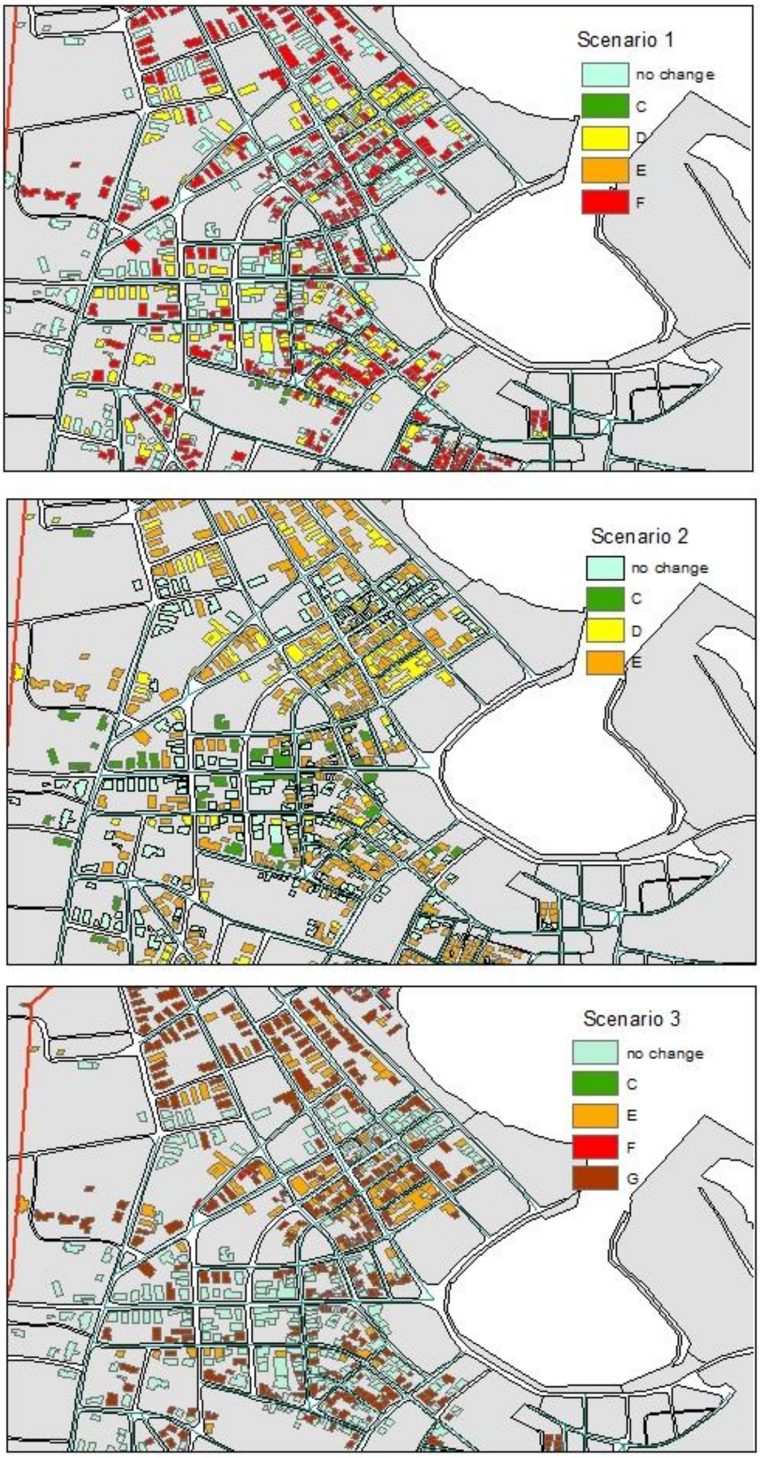

Figure 8 – Comparative views of the energy classification of the residential building stock after each intervention

4.2 Clustering of consumption

In order to understand the spatial distribution of consumption, a clustering analysis is taking place. The Moran's I statistic is drawn to decide on whether clusters are a result of complete spatial randomness or not.

In this case, Global Moran's I has a value of 0.2425, p-value is 0 and z-score=38.5, showing that the data are clustered with a chance of less than 1% that this is a result of randomness. Local indicators of clustering are also used to detect areas with excess consumption. Neighbourhoods that need immediate interventions are detected, where high consumption clustering is noted (Figure 9). In yellow colour, the individual buildings are shown, which may be targeted due their relatively high energy consumption compared to their neighbours.

Figure 9 – Neighbourhoods in need of immediate interventions, detected with clustering analysis

5. DISCUSSION

The results show that the current situation of the building stock is highly energy-consuming, due to the age of the constructions as well as the bad state of maintenance. In Sweden (Mata et al. 2013) the average annual primary energy calculated is 179 KWh/m^2, whereas in the study area it is calculated at 208 KWh/m^2. The northern European housing stock is considered to be performing better, as policies have already been implemented for building standards, subsidies and other incentives to promote energy efficiency (Voss-Uhlenbrock, et al., 1999; Balaras et al., 2005).

The energy balance findings follow the patterns of the Hellenic building stock, as described in Theodoridou et al. (2011). The greatest amount of energy consumption, around 70%, goes for space heating, due to the lack of insulation and double-glazing. Space cooling is accounting for 2.2% to 5.2% of total yearly consumption, as it is needed for only three months a year and is usually provided by relatively new and efficient air-conditioning units.

Buildings of archetypes A and B are proved to be the most energy-consuming, especially if no renovations have taken place throughout the years. These buildings should be prioritised by energy policies in order to maximise their effectiveness. The stock built after 1980 is performing better, as it is fully insulated, but the lack of the exploitation of solar energy and mostly the suffering from infiltration, due to the bad quality of the existing windows and doors result in low energy efficiency. The relation between the energy consumption of the building and the year of its construction appears to be very strong. This has to do with the change of building practices throughout the years, such as, the use of different materials and the emergence of more advanced electro-mechanical installations.

Due to do the fact that almost 66% of the housing stock is built before 1980 - in the period of no legal obligation for thermal insulation - the insulation intervention provides the greatest decrease of heating energy demand and consequently of total energy consumption at urban scale. According to Balaras et al. (2007) thermal insulation of the external walls of the buildings is the most effective intervention in Greece and specifically in climate zone A. It is also considered favourable due to the low cost for implementation; 50€/m^2 on average. The subsidisation of this intervention could be crucial in massively improving the energy performance of the residential building stock.

The solar thermal intervention is the one with the best results in improving the energy efficiency of each residence individually. In some of the existing old residences, owners have already implemented intervention 2, as it is more appealing to the individual owner, who sees a radical reduction to the electricity bill. It is observed that the intervention of solar thermal panels for DHW makes the most remarkable difference at an individual dwelling level, reducing total electrical energy consumption by 25-50% with a payback time of 2.5 years on average, according to the simulation results. This intervention is appealing to the individual owner and could be widely implemented without the need to be subsidised.

As for the proposed methodology, the database is simple and easy-to-build – especially for local authorities that in most cases already have the base-maps of the area and data on the geometrical characteristics, age, materials and state of the building stock. It can provide a good base on which to test and evaluate different policy measures and ensure their effectiveness. This concept is highly used in evaluating energy policies at international level (Caputo et al., 2013; Theodoridou et al., 2012).The use of building typologies is a widely approved methodology to massively evaluate energy consumption at urban scale. This approach is already in use by the Italian government for calculating cost-optimal levels of energy performance, complying with the Directive 2010/31/EU objectives, following the TABULA building-types.

This methodology combined with the use of GIS enabled the visualisation of the results, the analysis of spatial distribution patterns and the identification of areas of urgent intervention. Clustering analysis identified areas at excessive risk and great need for policy measures.

Different interventions could be formed and tested, based on the international good practice and by combining also cost-benefit analysis, as Goodacre et al. (2002) proposed for the UK, or by including the effect on the market value of the property (Zavadskas et al. 2008).

Further developments and improvements can be elaborated by incorporating more detailed input data about buildings and energy consumption. These are becoming more widely available, due to technological advances and increasing data from the ongoing energy audits – according to the EPBD framework. Also, the use of different simulation software, like Energyplus (Fumo et al. 2010), that can be adapted to every national context could make the tool more widely appealing. In this context, 3D city models could highly contribute to local governments' long-term energy policy and provide vigorous visualisations of the results of the various scenarios (Eicker et al., 2014), using the CityGML or some other semantic model, like IFC. Also, the level of automation of the tool could be improved in future studies and the use of Google Earth and StreetView can help in minimising the time-consuming field surveys. Following the INSPIRE (European Council, 2007) directive – about giving access to environmental data to the public and facilitating effective environmental planning – this methodology should be taken on the Web, creating a Web Mapping Service to provide easy and fast access to the data about energy consumption, classifications and benefits of different interventions. Making these data available to the public, promotes the concept of energy efficiency at a dwelling level, by informing them about the current situation of their property and how they could improve it.

6. CONCLUSIONS

This project presented and applied a bottom-up, engineering approach for mapping energy consumption and carbon emissions of the housing sector of the town of Kos, in Greece. Three retrofitting interventions were defined and implemented on the housing stock, the results of which were reviewed and discussed.

The housing sector in Greece is problematic in terms of energy consumption, with little use of the available renewable resources that needs to be improved, due to article 9 of the directive 2010/31/EU. New policies have to be implemented to improve the energy performance of buildings not only for environmental reasons and reaching the European goal of 20% CO_2 reductions but also for social reasons, due to the great risk of fuel poverty of the majority of the Greek households. In order to maximise the efficiency of these policies, this methodology proposes a way to target areas with high energy consumption.

The use of building typologies, adapted to the characteristics of the study area, proved to be efficient and in connection to GIS provides a way to compare different retrofitting interventions, observe the different results in space and detect areas at excess risk, where policies should be immediately implemented. Especially for the study area, results showed that future energy policies should target the older residential stock that appears to be the most energy consuming. A subsidies scheme focusing on improving the building envelope insulation could have the most radical results in decreasing energy consumption of the targeted area.

This methodology could be adapted to other cities and other national contexts, considering its special building characteristics and practices; with the use of different simulation software and building typologies. It is considered a cheap and fast solution especially for local authorities, which have the infrastructure and play an important role in the implementation of energy policies. It provides a way to analyse the existing stock and the energy consumption patterns, and also the means to classify the buildings in terms of energy performance and visualise the results of different retrofitting interventions. With this approach, energy planners, local administrators and other stakeholders can take more effective actions to minimise energy consumption at a city or neighbourhood level. An INSPIRE compliant solution would maximise the pace of changes in the residential sector, as the public becomes more informed and engaged to the project of zero-energy buildings.

REFERENCES

Balaras, C. A., Gaglia, G. G., Georgopoulou, E., Mirasgetis, S., Sarafidis, Y., Lalas, D. P., 2007. *European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings*, Building and Environment, 42, 1298-1314.

Balaras, C. A., Droutsa, K., Dascalaki, E., Kontoyannidis, S., 2005. *Heating energy consumption and resulting environmental impact of European apartment buildings*. Energy and Buildings, 37(5), 429-442.

Boardman, B., 2007. *Examining the carbon agenda via the 40% house scenario.* Building Research and Information 35 (4), 363-378.

Caputo P., Costa G., Ferrari S., 2013. *A supporting method for defining energy strategies in the building sector at urban scale.* Energy Policy, 55, 261-270.

Dall'O' G., Galante A., Pasetti G., 2012a. *A methodology for evaluating the potential energy savings of retrofitting residential building stocks.* Sustainable Cities and Societies, 4, 12-21.

Dall'O' G., Galante A., Pasetti G., 2012b. *A methodology for the energy performance classification of residential building stock on an urban scale.* Energy and buildings, 48, 211-219.

Daskalaki, E. G., Droutsa, K., Gaglia, A., Balaras, C.A., Kontoyiannidis S., 2011. *Building typologies as a tool for assessing the energy performance of residential buildings – A case study for the Hellenic building stock.* Energy and Buildings, 43, 3400-3409.

Eicker, U, Nouvel, R, Duminil, E, & Coors, V 2014, 'Assessing Passive and Active Solar Energy Resources in Cities Using 3D City Models', Energy Procedia, 57, 2013 ISES Solar World Congress, pp. 896-905, ScienceDirect, EBSCOhost, viewed 7 January 2015.

EN 15217. Energy Performance of Buildings – Methods for expressing energy performance and for energy certification of buildings, European Committee for Standardisation, Brussels, 2007.

European Council Directive 2002/91/EC of 16 December 2002 on the energy performance of buildings, OJ L 1, 4.1.2003, 65–71.

European Council Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings, OJ L 153, 18.6.2010, 13–35.

European Council. (2011). INSPIRE Road Map [electronic source] available at: http://inspire.jrc.ec.europa.eu/index.cfm/pageid/44 [accessed 15 July 2014].

Firth, S.K., Lomas, K.J., Wright, A.J., 2010. *Targeting household energy-efficiency measures using sensitivity analysis.* Building Research and Information 38 (1), 25-41.

Fracastoro, G. V., Serraino, M., 2011. *A methodology for assessing the energy performance of large scale building stocks and possible applications.* Energy and Buildings, 43, 844-852.

Fumo, N, Mago, P, & Luck, R., 2010. *Methodology to estimate building energy consumption using EnergyPlus benchmark models.* Energy and Buildings, 42 (12), 2331-2337.

Gouveia, J. P., Fortes, P., Seixas, J., 2012. *Projections of energy services demand for residential buildings: Insights from a bottom-up methodology.* Energy, 47, 430-442.

Heiple, S., Sailor, D. J., 2008. *Using building energy simulation and geospatial modelling techniques to determine high resolution building sector energy consumption profiles.* Energy and Buildings, 40, 1426-1436.

Hirst, E., 1978. *A model of residential energy use*. Simulation 30 (3), 540, 69-74.

Johnston, D., Lowe, R., Bell, M., 2005. *An exploration of the technical feasibility of achieving CO2 emission reductions in excess of 60% within the UK housing stock by the year 2050.* Energy Policy 33 (13), 1643-1659.

Jones, P., Patterson, J., Lannon, S., 2007. *Modelling the built environment at an urban scale - Energy and health impacts in relation to housing*. Landscape and Urban Planning 83, 39-49.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Djurovic- Petrovic, M., 2010. *A review of bottom-up building stock models for energy consumption in the residential sector*. Building and Environment 45, 1683-1697.

Kogiopoulos, K., 2011. [Kos 1912-1948: From occupation to annexation]. Vol. 1, 2. DOPABS, Municipality of Kos (In Greek).

Mastrucci, A., Baume, O., Stazi, F., Leopold, U., 2014. *Estimating energy savings for the residential building stock of an entire city: a GIS-based statistical downscaling approach applied to Rotterdam.* Energy &

Buildings, available at: http://dx.doi.org/10.1016/j.enbuild.2014.02.032, [accessed: 15 April 2014].

Mata, E., Kalagasidis, A.S., Johnsson, F., 2013. *A modelling strategy for energy, carbon, and cost assessments of building stocks.* Energy and Buildings, 56, 100-108.

Ministry of Environment, Energy and Climate Change (YPEKA), 2012. [Energy efficiency at buildings – The programme guide]. Athens: YPEKA (in Greek)

Natarajan, S., Levermore, G.J., 2007. *Predicting future UK housing stock and carbon emissions.* Energy Policy 35, 5719-5727.

Official Gazette of the Hellenic Republic, FEK 362/Δ`/4.7.1979, [Thermal insulation of buildings regulation]. Athens, 1979 (in Greek).

Official Gazette of the Hellenic Republic, FEK 89/A/2010, [N.3661/08 Harmonisation with Council Directive 2002/91/EC], 2002 (in Greek).

Official Gazette of the Hellenic Republic, FEK 407/B/2010, [Revised "regulations on buildings energy performance" (KENAK)], 2010 (in Greek).

Official Gazette of the Hellenic Republic, FEK 85/A/2010, [Article 10 of Law N.3851/2010 "Accelerating the development of renewable energy sources to tackle the climate change"], 2010 (in Greek).

Official Gazette of the Hellenic Republic, FEK 182/A/2010, [Article 28 of Law N.3889/2010 "Financing environmental interventions, green fund, ratification of forest maps and other provisions"], 2010 (in Greek).

Official Gazette of the Hellenic Republic, FEK 42/A/2013, [N.4122/13 Harmonisation with Council Directive 2010/31/EU], 2013 (in Greek).

Retsas, C., 2014. Proposal of Combined measures for eliminating the social environmental impact of informal development. Diploma thesis. National Technical University of Athens (in Greek).

Shorrock, L.D., Dunster, J.E., 1997. *The physically-based model BREHOMES and its use in deriving scenarios for the energy use and the carbon dioxide emissions for the UK housing stock.* Energy Policy 25, 1027-1037.

Shorrock, L.D., Henderson, J., Utley, J.I., 2007. *Reducing Carbon Emissions from the UK Housing Stock.* Building Research Establishment (BRE), Garston.

Swan, L.G., Ugursal, I. V., Beausoleil-Morrison, I., 2011. *Occupant related household energy consumption in Canada: Estimation using a bottom-up neural-network technique*, Energy and Buildings, 43, 326–337.

Schwartz, Y., Raslan, R., 2013. *Variations in results of building energy simulation tools, and their impact on BREEAM and LEED ratings: A case study*. Energy and Buildings, 62, 350-359.

Technical Chamber of Greece, Energy Performance of Buildings Directive – Technical Guidelines – T.O.T.E.E. 20701-1/2010 – Guidelines on the evaluation of energy performance of buildings, Athens, 2010 (in Greek)

Technical Chamber of Greece, Energy Performance of Buildings Directive – Technical Guidelines – T.O.T.E.E. 20701-2/2010 – Guidelines on the thermal properties of construction materials, Athens, 2010 (in Greek)

Technical Chamber of Greece, Energy Performance of Buildings Directive – Technical Guidelines – T.O.T.E.E. 20701-3/2010 – Guidelines on the Greek climatic data, Athens, 2010 (in Greek)

Technical Chamber of Greece, Energy Performance of Buildings Directive – Technical Guidelines – T.O.T.E.E. 20701-4/2010 – Guidelines on the energy audit procedure and the energy performance certificate, Athens, 2010 (in Greek)

Theodoridou, I., Karteris, M., Mallinis, G., Papadopoulos, A. M., Hegger, M., 2012. *Assessment of retrofitting measures and solar systems potential in urban areas using geographical information systems: Application to a Mediterranean city*. Renewable and Sustainable Energy Reviews, 16, 6239-6261.

Theodoridou, I., Papadopoulos, A.M., Hegger, M., 2011. *A typological classification of the Greek residential building stock*. Energy and Buildings, 43, 2779-2787.

Uihlein, A, Eder, P., 2010. *Policy options towards an energy efficient residential building stock in the EU-27.* Energy Build, 42, 791-798.

Voss-Uhlenbrock, H., Weber, C., Fahl, U., 1999. *International comparison of policy instruments for energy efficiency in residential space heating*. Panel 4 environmental perspective. In: Proceedings of the ECEEE 1999 summer study. Paris: European Council for an Energy Efficient Economy.

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