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Thermal Insulation Cost for the Total Building Potential in Greece: An Approximate Determination

*Giorgos P. Kouropoulos[1] & Marios Michelopoulos[2]

[1]B.Sc., Department of Energy Technology Engineering, Technological Educational Institution of Athens, Greece, *Corresponding Author E-mail: *etmecheng@gmail.com**

[2]B.Sc., Department of Civil Works and Infrastructure Technology, Technological Educational Institution of Athens, Greece, E-mail: *verdoffnikh@mail.com*

Abstract: In the present survey, the requirement cost for external thermal insulation in all existing buildings in Greece will be determined. Walls insulation and windows replacements including in the cost. The three basic characteristics of survey are statistical analysis, measurements and information that originate from statistical resources and some simplifying assumptions. The survey is consisted from four basic steps. It will initially become the estimation of number of existing buildings until 2010. In the second step will become the calculation of average volume that occupies each building in Greece and the numerical correlation of a building volume with insulation surfaces using statistical methodology. It follows the estimation of average cost of insulation materials per unit area in the third step. In the last step, the errors, results and numerical values replaced into an equation and the total thermal insulation cost will be calculated. The conclusions that arise are that the external thermal insulation cost of total building potential is estimated at 111.5 billion euros with a typical error of ± 20 % and totally corresponds to 60.62% of Greek GDP for 2013.

Keywords: Thermal Insulation, Heat Insulation in Greece, Energy Upgrade Buildings, Insulation Cost, Energy in Buildings

I. INTRODUCTION

In the last years in Greece, the heating oil prices increased, so there is imperative need to carry out the thermal insulation of buildings for reduction of heating load and heating cost of residences in Greece. The results from energy inspections in the buildings, indicate that only 2.1% of apartments have energy certificate with classification from B to A+ and the other 97.9% reminder have energy certificate with classification C or lower [1]. The state approves funds and subsidizes the citizens for the energy upgrade of their residences. The required thermal insulation cost for the total building potential is not known to date in Greece. This number is important as an order of magnitude and compared to the Greek gross domestic product. The cognizance of cost of total thermal insulation and energy improvement for building potential, can help the agencies of state in order to optimize the planning and funding approval process for thermal insulation in the residences of citizens in the future.

The first law that obliged constructors to implement thermal insulation in the new buildings, is the presidential decree 1979. The decree reports the regulation of thermal insulation of buildings (RTIB). This regulation was not applied correctly and lots of buildings presented inadequate insulation, that indicates from energy inspections in the buildings with year of construction 1980 [1]. The second law that was passed in Greece as contractual obligation of European directive, is the Regulation of the Energy Performance of Buildings (REPB) with law 3661/2008. This low applied from 2010 and legislated the job of energy building inspector. At this survey will be examined existing buildings with year of construction until 2010.

II. MATERIALS AND METHOD

A. Methodological approach

Quantitative statistical analysis is the basic method that is applied in this survey. In addition, will be used statistical data from other surveys and measurements such as housing census and statistical annuals yearbooks. The statistical errors of the survey will be determined and included at the final step of the survey. The analysis of research and calculation procedure for each step of survey is described below.

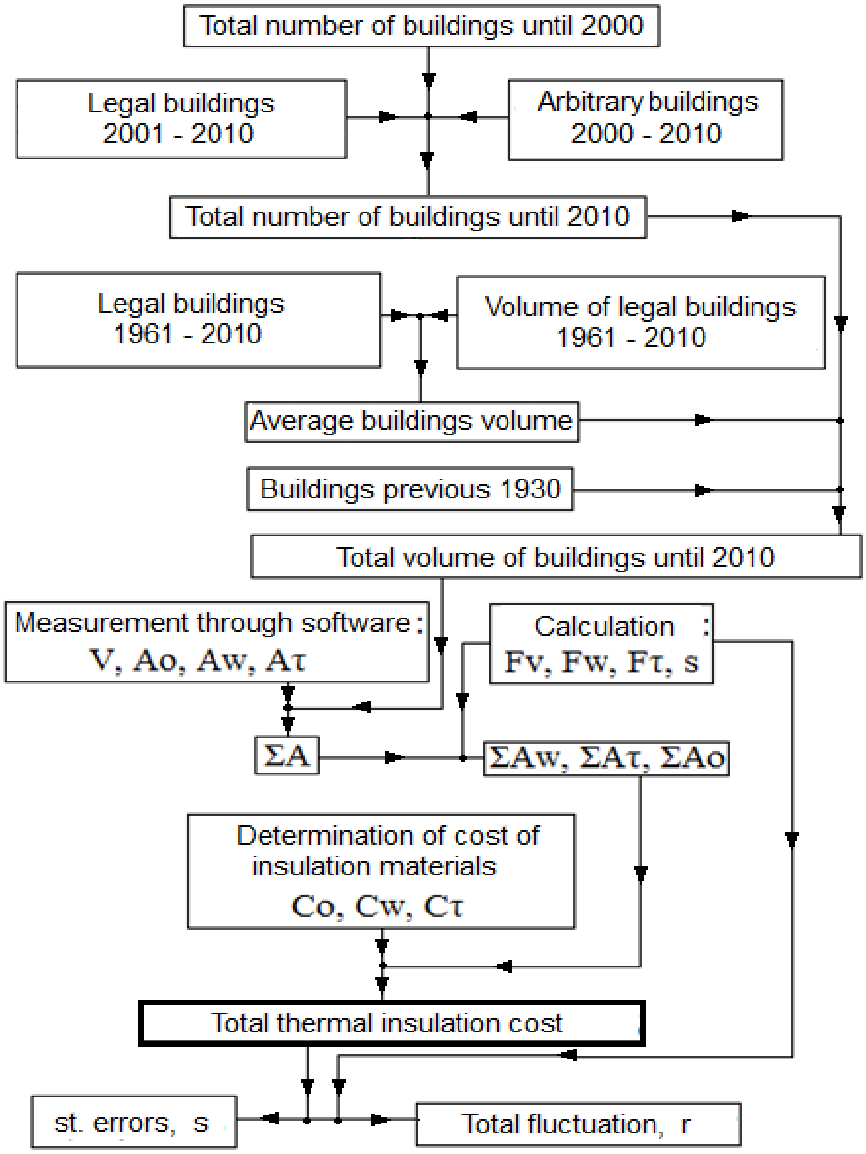

Figure 1. The progress of calculations.

B. Research assumptions and definitions

It is necessary to become some simplifying assumptions and approaches in this survey due to the lack of data, lack of measurements and bibliographical resources. There is an error that is created by certain assumptions. The final value of the total thermal insulation cost is increased by the error. That error is considered about $\pm$8.5%. Detailed data about the assumptions and statistical errors of research are reported below.

1. The average number of arbitrary buildings that were constructed in the period 2001-2010, was estimated by average population of arbitrary buildings per year for the period 1961-2000.

2. The average volume of all buildings in Greece is equal to the average volume of buildings that were constructed in the period 1961-2011.

3. The average volume of buildings with construction date before 1930 is increased by 30% in relation to the volume of buildings after 1930. This happens because lots of buildings with neoclassical architecture were taller by 1 – 1.5 m than newer buildings according to building regulation of this period that defined by royal decree 1919 and 1922 [21].

4. The volume of stairwell and liftwell upper/lower edge room is included in the buildings volume. Also, is included the volume of the floor addition in the future and volume of additional floor area or additional height area in the future. This volume reported in the statistical annuals yearbooks.

5. The average floor height in the buildings is considered equal to 3 meters. The height of ground floor in the certain buildings including shops and stores is considered equal to 4 meters.

6. The staircase volume and underground volume of a building, consists 12% of total building volume. This volume is subtracted by calculated volume of the buildings.

7. The total calculated insulation surface is increased by 4% due to internal staircase area and skylight area that osculates and get in touch with flat apartments. It is impossible to measure this insulation area by software.

8. The average measurement error for distance in the google earth software was measured -4.2%.

9. The 60% of property owners prefer internal thermal insulation due to lower cost and only 40% prefer external thermal insulation in the walls due to scaffolds installing.

10. General error of all simplifying assumptions, 8.5%.

Building nutshell or total thermal insulation surface. The total external surface that surrounds the building and interacts with external temperature of environment. Thermal flow it usually exists in the surface from internal to external space and reverse. The total thermal insulation surface is the sum of external wall surface, surface of windows and sheet glasses, external flat-roofs and ceilings surface of a building. In the next step, the total thermal insulation surface of buildings is distributed to individual surfaces.

III. CALCULATIONS AND NUMERICAL PROCCEDURE

A. Estimation of number of building potential in Greece

The total number of existing legal buildings and arbitrary buildings in Greece until 2010 is the most important information for estimation of the number of building potential. The results of the last housing census have been released since 2011 but do not give adequate information about the number of buildings. The housing census reports only the number of regular residences the number of apartments and flats in a building.

The number of regular residences does not help us to determine the thermal insulation cost in accordance with method and progress described in the Figure 1. The determination of thermal insulation cost by the number of regular residences requires more calculations and simplifying assumptions. As a consequence of this, the statistical error of the final value is higher than before.

The first assumption is related with determination of arbitrary buildings in the period 2001-2010. The total number of buildings which were constructed in 1961-2000 are 2693663 [2], the permitted buildings that were constructed at the same period amount to 1893053 [3] - [14]. The number of arbitrary buildings at the same period calculated by abstraction of two values. The arbitrary buildings in the period 1961-2000 amounts to 800610 with an average number of 20518 arbitrary buildings per year. Finally, there are 205280 arbitrary buildings in the period 2000-2010.

The number of all buildings that exists in Greece until 2000 amounts to 3990512 [2]. The legal buildings that were constructed in the period 2001-2010 amounts to 354503 [3] [4] [5] [6] and the number of arbitrary buildings in the period 2001-2010 is estimated at 205280. On the basis of the foregoing, it is concluded that the total number of buildings in Greece until 2010 is calculated from the sum of three values and amounts to 4550295 buildings.

Table 1. The estimated number of buildings in Greece

Time	*Reference*	*Number*
Total number of buildings until 2000	[2]	3990512
Buildings with permission in 2001-2010	[3] [4] [5] [6]	354503
Arbitrary buildings in 2001-2010	Assumptions 1, 2	205280
Total number of buildings until 2010	Approximate	4550295

B. Estimation of average building volume and total volume of the buildings

The average volume that occupies the buildings in Greece is the second most important information in this study. The estimation of building volume is possible from the provided information of statistical annual yearbooks. The yearbooks releases by the national statistical authority. The annual yearbooks report only the volume of legal existing buildings and expansions or additions that carried out. Most of buildings before 1950 in Greece were demolished. So, the determination of average building volume in Greece, resulting by processing data of legal constructed buildings and the permitted floor additions or expansions in the period 1961-2011. This means that the second simplifying assumption will be applied.

The total number of legal constructed buildings in period 1961-2011 amounts to 2338068 buildings. The volume that occupy the buildings together with permitted floor additions amounts to 2933541×10^3 m^3 at the same period [8 – 18]. A percentage of 12% to be deducted from the average value of buildings volume that results, this defined from sixth assumption of the survey. The average buildings volume is equal to:

$$\bar{V} = \frac{2933541 \times 10^3\ m^3}{2338068 \text{ buildings}} \times (1 - 0.12) = 1104.12 \frac{m^3}{\text{building}} \quad (1)$$

Table 2. The volume of buildings which constructed before and after 1930

Time period	*Buildings number*	*Increasing factor*	*Average volume (m^3)*	*Total buildings volume (m^3)*
Before 1930	372320	1.3	1435.36	534413×10^3
1930 – 2010	4177975	-	1104.12	4612986×10^3
Sum	4550295	-	-	$\mathbf{5147444 \times 10^3}$

According to Table 2, the average volume of buildings before 1930 increased by 30%. The buildings which were constructed in Greece before 1930 amounts to 372320 [2] and the total number of buildings until 2010 are estimated to 4550295 (see Table 1).

$$V = 1104.12 \frac{m^3}{\text{building}} \times 4177975 + 1435.36 \frac{m^3}{\text{building}} \times 372320 = 5147444 \times 10^3\ m^3 \quad (2)$$

C. Correlation of building volume with total insulation surface

At this step of research, it must be found the numerical correlation between the total thermal insulation surface and total volume of a building. If the correlation between building volume and insulation surface is known, then the total thermal insulation surface can be determined from the total buildings volume. After the determination of total insulation surface, must be implemented the distribution of surface to the different kind of external surface. There are several different external surfaces depending on the building component and the type of insulation such as external wall insulation, internal insulation, roof insulation or windows replacement. Each insulation type in the building has different cost.

The statistical data of issued energy certificates that related with external buildings surfaces have not published by the Ministry of Environment Energy and Climate Change. These data regard the external building surface that presents heat transmission and interacts with external environment. Consequently, it is necessary to conduct measurements through the "google earth" software. The basic negative effect of this method is the measurement error that exist on the satellite photomaps of the software. The error influences the final value of total thermal insulation cost. The area of external surfaces of each building is determined from the floor plan in the google earth. With regard to the height of buildings, there is the fifth simplifying assumption. The values, geometric characteristics and building external surfaces as well as their symbolization are as follows:

V: Total building volume in m^3 (without lift well upper edge room on the terrace).

A_O: Total external area of building that interacts with environment, in m^2.

A_W: Windows and sheet glasses surface, in m^2.

A_T: Terrace surface of the building, in m^2.

F_V : The ratio A_O/V, is the total external surface per $1m^3$ building volume.

F_W: The ratio $A_W/0.917A_O$ is the percentage of windows and sheet glasses surface to the total building insulation surface. The value 0.917 is called area correction factor. This factor can be calculated by comparing the floor plan of a real building and floor plan of the same building on the satellite photomap. The error is about -4.2% for one dimension, so two dimensional correction factor is equal to $(1-0.042)^2 = 0.917$.

F_T: The ratio A_T/A_O and gives the percentage of terraces and external ceilings surface to the total building insulation surface.

The ratio F_V gives the desired numerical correlation between total building volume and total external surface of building. There is a sample of 60 randomly buildings which will be examined by google earth. Analytically, the distribution percentage of the buildings in the sample, are the same as the housing census [2]. So, 55 buildings or 91.6% are residences and 4 of them are neoclassical residences. The 5% or 3 buildings are office buildings and the 3.4% or 2 buildings are shops. The 5% of buildings are founded in Thessaloniki and remaining 95% are founded in Athens. The measurements are presented in the Table 3.

Table 3. Measurements in the buildings by Google Earth software

A/A	V (m^3)	A_O (m^2)	A_W (m^2)	A_T (m^2)	F_V	F_W (%)	F_T (%)
1	2589.0	752.8	153.4	174.6	0.29	20.4	23.2
2	1993.1	617.8	142.9	107.1	0.31	23.1	17.3
3	3426.7	615.6	118.9	155.8	0.18	19.3	25.3
4	3407.5	812.5	150.3	126.0	0.24	18.5	15.5
5	2995.2	425.4	26.7	61.4	0.14	6.3	14.4
6	3138.0	755.4	85.7	191.0	0.24	11.3	25.3
7	600.0	76.0	38.7	54.3	0.13	50.9	20.4
8	6084.0	1167.1	270.8	287.3	0.19	23.2	24.6
9	1120.0	293.0	34.5	160.0	0.26	11.8	54.6
10	1954.2	361.9	50.2	102.5	0.19	13.9	28.3
11	729.1	121.9	13.2	58.8	0.17	10.8	48.2
12	3756.6	679.9	118.6	196.3	0.18	17.4	28.9
13	6446.7	2110.5	442.4	470.6	0.33	21.0	27.7
14	4875.3	900.7	253.7	226.5	0.18	28.2	25.1
15	4120.3	763.4	236.1	242.1	0.19	30.9	31.7
16	57195.0	6617.8	892.0	1982.8	0.12	13.5	30.0
17	5634.3	1392.6	255.3	263.2	0.25	18.3	18.9
18	4071.4	1059.7	71.9	197.8	0.26	6.8	18.7
19	5999.8	1049.9	249.6	289.1	0.17	23.8	27.5
20	1640.5	263.9	69.2	71.1	0.16	26.2	26.9
21	7544.3	1507.9	442.6	219.7	0.20	29.3	14.6
22	3579.6	784.1	170.3	160.1	0.22	21.7	20.4
23	4811.7	755.7	117.9	179.6	0.16	15.6	23.8
24	663.3	171.1	28.1	90.8	0.26	16.4	53.1
25	1966.5	574.1	114.4	118.0	0.29	19.9	20.6
26	889.6	295.9	27.2	141.8	0.33	9.2	47.9

27	311.4	227.8	13.8	49.9	0.73	6.1	21.9
28	1360.8	455.9	65.5	136.1	0.34	14.4	29.9
29	669.3	404.8	38.0	110.6	0.60	9.4	19.2
30	2954.4	544.3	128.4	124.7	0.18	23.6	22.9
31	3659.3	613.4	136.8	210.2	0.17	22.3	34.3
32	2112	852.8	147.2	158.4	0.40	17.3	18.6
33	1592	646.4	103.0	84.6	0.41	15.9	13.1
34	4930.8	1648.6	216.3	493.1	0.33	13.1	17.6
35	2704.8	809.3	77.1	158.0	0.30	9.5	19.5
36	5340.2	1164.3	144.4	254.9	0.22	12.4	21.9
37	2394.0	524.4	66.0	113.1	0.22	12.6	21.6
38	416.5	156.6	26.3	53.6	0.38	16.8	34.2
39	402.5	105.1	12.3	59.7	0.26	11.7	56.8
40	1728.0	591.4	95.6	95.0	0.34	16.2	16.1
41	1171.6	563.3	68.9	106.5	0.48	12.2	18.9
42	883.5	396.8	52.1	83.7	0.45	13.1	21.1
43	1489.8	566.0	124.0	129.6	0.38	21.9	22.9
44	960.0	329.4	62.6	72.0	0.34	19.0	21.9
45	1242.0	369.9	90.5	94.2	0.30	24.5	25.5
46	937.5	297.1	38.8	84.4	0.32	13.1	28.4
47	960.0	327.4	25.1	108.0	0.34	7.7	33.0
48	801.1	323.7	24.4	110.9	0.40	7.5	34.3
49	1551.0	565.2	120.6	148.5	0.36	21.3	26.3
50	1128.0	356.7	26.9	108.0	0.32	7.5	30.3
51	1134.0	364.1	76.3	170.1	0.32	21.0	46.7
52	1068.8	308.5	36.6	106.9	0.29	11.9	34.6
53	627.0	316.5	33.0	94.1	0.50	10.4	29.7
54	2808.0	763.7	120.6	149.2	0.27	15.8	19.5
55	1224.0	395.6	47.6	91.8	0.32	12.0	23.2
56	1980.0	476.1	124.8	92.4	0.24	26.2	19.4
57	1863.0	735.1	87.9	182.2	0.39	12.0	24.8
58	5376.0	941.1	130.8	285.6	0.18	13.9	30.3
59	2640.0	567.9	41.0	158.4	0.22	7.2	27.9
60	5040.0	1019.0	184.5	252.0	0.20	18.1	24.7
AVG	–	–	–	–	0.29	16.8	27.1
s (%)	–	–	–	–	±5.1	±5.9	±4.9

The conclusion that arises from the process of measurements and statistical analysis is that the 1 m^3 of a building volume in Greece, corresponds to 0.29m^2 total external surface. A percentage of 16.8% of 0.29m^2 corresponds to the windows and sheet glasses surface. A percentage of 27.1% corresponds to the terrace or flat roof surface. The remaining 56.1% corresponds to the vertical non-transparent structural elements, that is, external walls of building. The definitions of transparent and non-transparent structural elements as well as vertical and horizontal elements are described in the Regulation of Energy Performance in the Buildings [19]. The typical errors of statistical analysis in the sample are 5.1%, 5.9% and 4.9% respectively.

Table 4. Percentage distribution of external thermal insulation surfaces for building potential according to measurements.

Direction of structural elements (REPB)	*Name of structural elements (REPB)*	*Type of external building surface*	*Percentage (%)*
Vertical	Transparent	Windows, sheet glass	16.8
	Non-transparent	External walls	56.1
Horizontal	Non-transparent	Terraces, roofs	27.1

The following equation shall be applied to the building external surfaces.

$$\Sigma A = \Sigma A_W + \Sigma A_T + \Sigma A_O \quad (3)$$

Total external building surface:

$$\Sigma A = 5147444 \times 10^3\ m^3 \times 0.29 \frac{m^2}{m^3} \times (1 + 0.04) = 1552469 \times 10^3\ m^2 \quad (4)$$

Surface of windows and sheet glasses:

$$\Sigma A_W = 0.168 \times \Sigma A = 1552469 \times 10^3\ m^2 \times 0.168 = 260815 \times 10^3\ m^2 \quad (5)$$

Terraces and flat roofs thermal insulation surface:

$$\Sigma A_T = 0.271 \times \Sigma A = 1552469 \times 10^3\ m^2 \times 0.271 = 420719 \times 10^3\ m^2 \quad (6)$$

External walls surface:

$$\Sigma A_O = 0.561 \times \Sigma A = 1552469 \times 10^3\ m^2 \times 0.561 = 870935 \times 10^3\ m^2 \quad (7)$$

D. The cost of insulation materials

At this step will become a market research about fluctuation of cost of insulation materials per unit area. There are different types of insulation materials. The cost of thermal insulation varies depending on the quality and thermophysical properties of a material, that is, density, thermal conductivity, specific thermal resistivity, specific heat capacity and water tightness factor [23]. There is a convergence between the cost of materials of insulation commercial companies and the indicative cost of insulation by the Greek Ministry of Energy. Those prices shall be valid for the subsidized projects for thermal insulation in the buildings in Greece [20]. See Table 5.

Table 5. Cost of insulation materials for transparent and non-transparent structural elements.

Insulation type	*Cost (euro/ m^2)*
External roof insulation	40
External wall insulation	50
Internal insulation (wall-roof)	25
Sliding windows/frames	250
Hinged windows/frames	280
Sheet glass replacement	75

Whereas the ninth simplifying assumption, the average thermal insulation cost for external walls C_O, is equal to:

$$C_O = 0.4 \times 50 \frac{\text{euro}}{m^2} + 0.6 \times 25 \frac{\text{euro}}{m^2} = 35 \frac{\text{euro}}{m^2} \tag{8}$$

In the buildings before 1970, there are not sliding windows but hinged windows from wood. Almost all the buildings after 2000 there are hinged windows. After the data processing of [2] and the first step of survey, it is concluded that the percentage of buildings with sliding windows amounting to 45.7% and the buildings with hinged windows are 44.3%. The remaining 10% of property owners prefer a simple replacement of sheet glass. Consequently, the average cost C_W for energy upgrading of windows and sheet glasses is:

$$C_W = 0.457 \times 280 \frac{\text{euro}}{m^2} + 0.443 \times 250 \frac{\text{euro}}{m^2} + 0.1 \times 75 \frac{\text{euro}}{m^2} = 246.2 \frac{\text{euro}}{m^2} \tag{9}$$

The cost C_T for terrace and roof thermal insulation is equal to: 40 euro/ m^2 (10).

E. Final calculations and error assesment

The total thermal insulation cost of the total building potential is calculated by (10):

$$\Sigma C = \Sigma A_W C_W + \Sigma A_T C_T + \Sigma A_O C_O \tag{11}$$

If we replace the values of equations (4) (5) (6) (8) (9) (10) to (11), the total thermal insulation cost ΣC, shall be calculated:

$$\Sigma C = 111553477.8 \times 10^3 \ euros \tag{12}$$

In the Table 5, three different typical errors about F_V F_W F_T are referred. In the equation (3), F_V with average value 0.29 has a typical error ±5.1%, this error can be expressed as proliferation into an absolute as 0.29×$|1.051|$, this error affects the result of equation (12). In the equation (4), F_W with average value 16.8 has a typical error ±5.9%, this error can be expressed as proliferation into an absolute as $0.168 \times |1.059|$, the error affects the result of equation (12), that is $|1.059| \Sigma A_W C_W$. Exactly the same happens about typical error ±4.9%, that is $|1.049| \Sigma A_T C_T$. The coefficient ΣA_O in the equation (11), is calculated as follows: 100% - 27.1% - 16.8% = 56.1% (13). If the above errors enters into the previous values in (13) then will have the following calculations:

$$\begin{gathered} 100\% - |1.049| \times 27.1\% - |1.059| \times 16.8\% = \\ 1 - |1.049| \times 0.271 - |1.059| \times 0.168 = \\ 1 - |0.284| - |0.178| = \\ -1 + |0.284| + |0.178| = \\ -1 + |0.284 + 0.178| = \\ -1 + |0.462| = 1 - |0.462| = \\ 1.462 \ (rejected > 100\%) \ or \ 0.538 \ (accepted) \end{gathered} \tag{14}$$

Now checking the divergence between 0.561 and 0.538, the divergence is 1 - 0.561/0.538 = 0.041 or 4.1%. This error in the case, it can be expressed as proliferation into an absolute in equations (6) and (11), that is $|1.041| \Sigma A_O C_O$. Furthermore, according to tenth assumption, there is an error 8.5% that can be expressed in equation (11), that is $|1.085|$. The final form of equation (11) for calculating the total insulation cost by minimum and maximum divergence is follow:

$$\Sigma C' = |1.085| \times |1.051| \times (|1.059|\Sigma A_W C_W + |1.049|\Sigma A_T C_T + |1.041|\Sigma A_O C_O) \Leftrightarrow$$
$$\Sigma C' = |1.208|\Sigma A_W C_W + |1.196|\Sigma A_T C_T + |1.187|\Sigma A_O C_O \Leftrightarrow$$
$$\Sigma C' = (|1.208| \times 63505074 + |1.196| \times 16643360 + |1.187| \times 30146900) \times 10^3 \Leftrightarrow \quad (15)$$
$$\Sigma C' = 1.0114 \times (|76714130| + |19905459| + |35784370|) \times 10^3 \Leftrightarrow$$
$$\Sigma C' = |133914295 \times 10^3| \text{ euros}$$

The final error assessment for total thermal insulation cost, including all errors of this research is:

$$r = \frac{\Sigma C'}{\Sigma C} = \frac{|133914295 \times 10^3|}{111553478 \times 10^3} = |1.2| \ \ or \ \pm 20\% \quad (16)$$

IV. CONCLUSIONS

The total thermal insulation cost of building potential in Greece varies from 88.2 to 132.4 billion euros with an average estimation of 111.5 billion euros, including wall insulation windows replacements and glass replacement. The average thermal insulation cost per buildings until 2010, amounts to 24515 euros. About the correspondence between GDP and total insulation cost, the total cost of thermal insulation for building potential, corresponds to 60.57% of gross domestic product in 2013 [22]. Is imperative need to become a re-appraisal of the cost of thermal insulation for Greek buildings in the future if we want to reduce the fluctuation and statistical errors. The available statistical data from 500000 issued energy performance certificates or 15% of total buildings population, are inadequate for precise determinations with low statistical and measurement errors.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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