# A multi-objective optimization approach for improving energy efficiency of buildings in Greece

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**Summary: Description of the problem**: The energy problem is our daysis one of the most important issues of the global community.The Buildings sector is one of the main energy consumers. The existing building stock across Europe consumes about 40% of final energy consumption of EU member states. For this reason, the EU led to the decision to adjust its energy policy focusing on energy upgrading of existing buildings. (Revised European energy performance of buildings Directive 2010/31 / EU)[1].
The energy upgrade can be achieved by implementing various intervention techniques, taking into account environmental, energy, economic, socialfactors and legal arrangements.The combination of these factors and theirinclusion in the process decision, will lead to the optimal solution for the consumer

**Approach**: In this paper we focus on the existing process concerning the energy upgrade problem in Greece. Checking whether or not taken into account simultaneously the above decision criteria of Energy Efficiency Measures (EEM) on Energy Audits. A Decision-making algorithm is proposed concerning the Energy Efficiency Measures, taking into account all criteriaby weighting factors, approaching the problem as multi-objective.

**Results and Conclusions:** We compare the results of the two methods, and we conclude that the current software using by the Energy Audits in Greece deviates significantly from the optimal solution concerning EEMwhich is obtained by applying the algorithm, causing finally energy and economic cost. To export results and consequently conclusions, we apply the two methods approach on a random sample of professional building.

## 1.Introduction

Reducing energy consumption and prevent energy waste is a major objective of the European Union (EU).
The existing building stock across Europe consumes about 40% of final energy consumption of EU member states.
The final consumption of energy in Greek buildings is about 34%, according to the latest published data for 2007. The Greek buildings consume around 67% of electricity and contribute approximately 43% to the totalemissions of carbon dioxide released into the atmosphere [2]

The possibilities of Energy Safe in the building sector in our country is very high and can be easily exploited by applying appropriate measures. Approximately 71% of Greek buildings were built before 1980, have no insulation measures and have a low energy efficiency, while most have old E/M installations. Also 77% of Greek buildings corresponds to residential buildings and 23% in the tertiary sector buildings[3].
To estimate the potential of energy savings in buildings sector, studied the implementation of various energy-saving measures in αproject prepared for the Ministry of Environment, Planning and Public Works[3,4]
In the context of harmonization of Greece to the European standard 2010/21 / Eu, was established the process Energy Inspectors of Building. This process isprepared by certified engineers, named Inspectors of Buildings Energy (IBE). The auditor, through this process, firstly determines the energy requirements of the building and then proposesEEM to achieve energy improvement of the building. The process which is following until now is the IBE to choose empirically the EEM aiming to optimize the environmental, energy, economic and legal regulations
This empirical method uses as Decision-making algorithm, the experience and the analytical thinking of each IBE. That sure leads to multiple solutions of thee problem without checking in any way if they are optimal solutions.
For this reason, it is proposed an alternative approach of the problem. This approach concerns the solution of a mathematical model which includes all the decision-making criteria. These criteria are expressed through objective functions and constraints, while the solution of the mathematical model will be the best combination of each material concerning the proposed EEM.

## 2.Overview

The EEM that can be applied to optimize the energy consumption of buildings can be divided into the following categories:

- Measures that interferes the structure of the building (e.g. insulation, color etc.).
- Measures that interferes heat and cooling loads (bioclimatic architecture, etc.) [8]
- Measures that optimize comfort conditions combined with minimal energy requirements [9]
- Energy consumption management through smart automation systems [10]

The IBE considering all these options should assess empirically and suggest combination of EEM to achieve optimal multicriterion result. The approach of the problem as is applied in our days in Greece is the energy simulation of the building using certified software TEE KENAK.

By following this methodology is not ensured that the optimum energy potential measure of energy safe is selected. This is the reason which a study took place on behalf of the Ministry [3,4], in order to estimate the energy savings potential of each EEM in each building category. The Hans Erhorn [11], as part of the same problem formed the Energy Concept Adviser, which helps in making decisions about the most effective energy upgrades in educational buildings. The abundance of material selection in each EEM in combination with the number of criteria raises the problem even more complicated. The Ehsan Asadi [12] created a mathematical model of multi-criteria optimization, operating aids in the evaluation process of technical options to minimize energy use in a cost effective manner while meeting the demands of consumers.

## 3. Multi-criteria approach to the problem

### *3.1 Multicriteria Analysis application on energy upgrade of buildings*

The multi-criteria analysis in this paper is to address the problem of cost of Energy Efficiency Measures in buildings as well as users desire translating each once in weighting factors (w).

The approach is an optimization of multiple targets (multi-objective optimization) combining the KENAK software (for energy simulation of the building), with the Matlab software (the mathematical model solving tool we specify). Applying the routine shown in Figure 1. leads to cost optimizationand energy saving in buildings depending on the consumers needs, within the MCA.

Alternative energy solutions are predetermined and decision variables will be a wide range of materials of predefined alternatives.

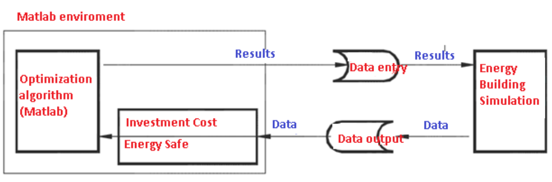



*Figure 1*
*Data Algorithm*

### *3.2The proposed Multi-objective approach*

In this section will be defined decision variables, objective functions, constraints and finally the mathematical modeling of the problem that lead to the desired solution *3.2.1 Decision variables*

To reduce the possibility that the optimal solution not be selected in our scenario, we look at statistical data of the Ministry of Environment, Planning and Public Works of "Assumptions Annual energy savings per climate zone for the relevant EEM in school buildings in 2010".

We select the first three EEM according to the classification of the Ministry study [3,4], depending on the type of building that we study. The decision variables are i for the first EEM, j for the second EEM and k for the 3rd EEM.

#### *3.2.2 Objective Functions*

The objective functions describes mathematically the criteria taken into account, as a function of the decision variables.

<u>Investment costs by implementing ESM (ReCost)</u>

$$ReCost = A_{EWALL} \times \sum_{i=1}^{I} C_i^{EWALL} + A_{ROF} \times \sum_{J=1}^{j} C_J^{ROF} + A_{WIN} \times \sum_{k=1}^{K} C_k^{WIN} \quad (1)$$

$A_{EWALL}$ surface of the exterior walls ($m^2$)

$C_i^{EWALL}$ cost in (Euro / m2) every exterior wall insulation material

$A_{ROF}$ roof surface ($m^2$)

$C_J^{ROF}$ cost in (Euro / m2) every roof insulation material

$A_{WIN}$ window surface ($m^2$)

$C_k^{WIN}$ the costs (Euro / m2) every type of window

<u>Energy Safe (ES)</u>

$$ES = E_{pre} - E_{post} \quad (2)$$

$E_{pre}$ Energydemandsof the building before the implementation of the ESM

$E_{post}$ energy demand of the building after the implementation of the ESM

The actual energy consumption of the building, determined by the software TEE KENAK, simulating the building. The calculations have taken into account the energy demand of the building in heating, in cooling and in lighting. Thus, the energy requirements of the building, either before or after implemented the ESM, identified through the equation:

$$\boldsymbol{E = E_{heat} + E_{cool} + E_{ligh}} \quad (3)$$

$E_{heat}$ the energy requirements to heat the building (KWh/$m^2$)

$E_{cool}\,E_{heat}$ the energy requirements to cool the building(KWh/$m^2$)

$E_{ligh}\,E_{heat}$ the energy requirements to light the building (KWh/$m^2$)

Energy requirements after implementing the ESM are determined by using the software TEE KENAK, choosing each time a different combination of material of each ESM

#### *3.3.3 Multicriteria optimization approach by studying the simultaneous effect of variables*

In this section an optimization approach to the problem happens, taking into account all possible combinations of materials,

$$MinReCost_{sim} = \text{Min}(\text{ReCost}(i,j,k,)) \quad (4)$$
$$MaxES_{sim} = \text{Max}(\text{ES}(i,j,k,)) \quad (5)$$
$$\text{OptimumZ1} = \boldsymbol{w_1} \times MinReCost_{sim} + \boldsymbol{w_2} \times MaxES_{sim} \quad (6)$$

Όπου

$\boldsymbol{w_1}$ = cost weighting factor investment

$\boldsymbol{w_2}$ = energy saving weighting factor

$$\sum_{i=1}^{2} w_i = 1 \quad (7)$$

i∈ $(\boldsymbol{1}, \boldsymbol{2}, \ldots . . \boldsymbol{I})$

j∈ $(\boldsymbol{1}, \boldsymbol{2}, \ldots . . \boldsymbol{J})$

k∈ $(\boldsymbol{1}, \boldsymbol{2}, \ldots . . \boldsymbol{K})$

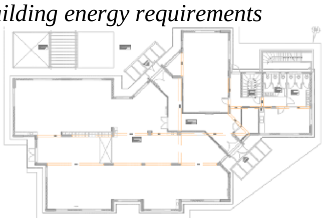
## 4. Case Study

In this section, the existing method of approaching the problem, is implemented, by using software of TEE KENAK on an existing professional building.
The multicriteria methodology will also be applied on the same building.
After all results are quoted.

### *4.1Determination of building energy requirements*

**Description of the building**

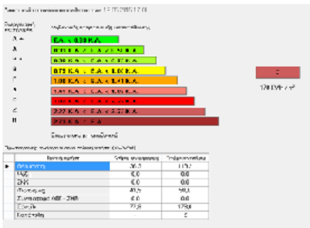
**Building classification: School**
**Area : Xanthi - climate zone C**
**Floors: ground floor**
**Total area of the building: 535m2**
**Age of the building: 1979**
**Height of the building: 8m**
**Type of construction : Common**



**Energy classification of the building using software TEE KENAK**

***Energy Requirements***

**Ideal building : 77,8 KWh/m2**
**Existing bulding: 178 KWh/m2**
**Existing building: 95230 KWh**
**Bulding classification: Z**



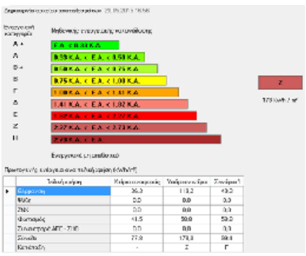
### *4.2Recommended ESM according to the engineer crisis*

The material i = 4, ie Expanded polystyrene 0.1m thick.
The material j = 4, ie Expanded polystyrene 0.08m thick.
The material k = 1, ie metal frame with thermal break and air gap 6mm

**Energy classification of the building using software TEE KENAK by applying ESM**

***Energy Requirements***

**Ideal building : 77,8 KWh/m2**
**Existing bulding: 99,1KWh/m2**
**Existing building:53018,5 KWh**
**Bulding classification: C**



### *4.3Approaching the problem by using the multicriteria method*

Applying on software TEE KENAK each possible combination of materials concerning ESMs, revealed numerous of data concerning energy safe, which indicatively presented on the following table:

Πίνακας 9.2.1

Epost(KWh/m²)- Energy requirements by applying ESM

i=1 έως 6, j=1 έως 6, k=1

| j,k | 1,1 | 2,1 | 3,1 | 4,1 | 5,1 | 6,1 |
|---|---|---|---|---|---|---|
| i | | | | | | |
| 1 | 115,8 | 107,4 | 116,8 | 107,6 | 114,1 | 106,4 |
| 2 | 111,3 | 102,8 | 112,3 | 103 | 109,5 | 101,7 |
| 3 | 110,1 | 101,6 | 111,1 | 101,7 | 108,2 | 100,5 |
| 4 | 107,5 | 98,9 | 108,5 | 99,1 | 105,6 | 97,8 |
| 5 | 109,9 | 101,4 | 111 | 101,6 | 108,1 | 100,3 |
| 6 | 107,4 | 98,8 | 108,4 | 99 | 105,5 | 97,7 |

In correspondence, revealed numerous of data concerning Investment Costwhich indicatively presented on the following table:

Πίνακας 9.2.13

ReCost(Ευρώ)- Investment Cost by applying ESM

i=1 έως 6, j=1 έως 6, k=1

| j,k | 1,1 | 2,1 | 3,1 | 4,1 | 5,1 | 6,1 |
|---|---|---|---|---|---|---|
| i | | | | | | |
| 1 | 36164 | 43189 | 33312 | 36726 | 35463 | 41798 |
| 2 | 39283 | 46308 | 36432 | 39845 | 38582 | 44917 |
| 3 | 35716 | 42741 | 32865 | 36278 | 35016 | 41350 |
| 4 | 37428 | 44453 | 34577 | 37990 | 36727 | 43062 |
| 5 | 38966 | 45991 | 36115 | 39528 | 38265 | 44600 |
| 6 | 43119 | 50144 | 40268 | 43681 | 42419 | 48753 |

All data are registered in Matlab software, subroutines are used as shown in the following figure, weighting factors w1 = 0.5 and w2 = 0.5, ie giving equal weight both of criteria, the results are shown as follows

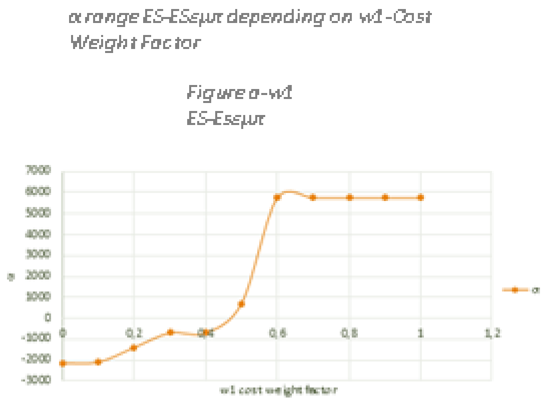
```
for i = (1:6)
    for j = (1:24)
            multi_objective_optimization = weighting_vect
            if ((i == 1) & (j == 1))
                min = multi_objective_optimization;
                min_cost = Cost(i,j);
                max_es = ES(i,j);
                i_min = 1;
                j_min = 1;
            else
                if (multi_objective_optimization < min)
                    min = multi_objective_optimization;
                    min_cost = Cost(i,j);
                    max_es = ES(i,j);
                    i_min = i;
                    j_min = j;
                end
            end
    end
end

min_cost
max_es
i_min
j_min
```

Chosen materialsi=3, j=4, k=3
Minimum Cost of Investment
(MinReCost)sim = 24579 Euro
Maximum Energy Safe
(MaxES)sim = 41516KWh
At the following table there are presented the chosen materials following all the possible combination of weighting factors,

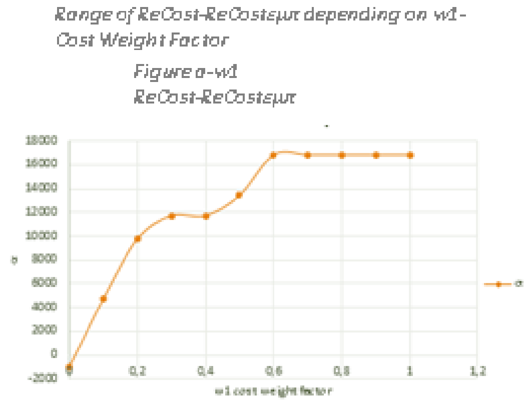
Table of materials - Combination of weight factors

| α/α | w1 | w2 | Recost (Ευρώ) | ES (KWh) | i | j | k |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 39004 | 44152 | 6 | 6 | 4 |
| 2 | 0,1 | 0,9 | 33313 | 44298 | 4 | 6 | 4 |
| 3 | 0,2 | 0,8 | 28241 | 43603 | 4 | 4 | 4 |
| 4 | 0,3 | 0,7 | 26291 | 42907 | 4 | 4 | 3 |
| 5 | 0,4 | 0,6 | 26291 | 42907 | 4 | 4 | 3 |
| 6 | 0,5 | 0,5 | 24579 | 41516 | 3 | 4 | 3 |
| 7 | 0,6 | 0,4 | 21166 | 36487 | 3 | 3 | 3 |
| 8 | 0,7 | 0,3 | 21166 | 36487 | 3 | 3 | 3 |
| 9 | 0,8 | 0,2 | 21166 | 36487 | 3 | 3 | 3 |
| 10 | 0,9 | 0,1 | 21166 | 36487 | 3 | 3 | 3 |
| 11 | 1 | 0 | 21166 | 36487 | 3 | 3 | 3 |

## 5. Compare Results-Conclutions




Comparing the results between the empirical method and the multi-criteria algorithm method, we conclude that the materials which had empirical been chosen i=4, j=4, k=1 ES=42.211,5Kwhandι ReCost=37.990Euro, are not the best solution in any combination weighting.




As observed, the smallest energy differences are in the area w1 =0,2 to 0,4. This means that our empirical selection achieves the smaller energy differences than the respective best solutions for w1 = 0,2, 0,3 and w1 = 0,4, i.e emphasizing respectively 80%, 70% and 60% savings energy.

The divergence is -695,5 KWh, -695,5 KWh and 695,5 KWh energy savings respectively. As regards the investment costs divergence from the corresponding optimal solutions in 11.699Euro, 11 699 Euro and 13 411 Euro. Namely, costing the project in about 12.000Euro more than could be achieved by using the optimization algorithm

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