Zero Energy Buildings-ZEB or Nearly Zero Energy Buildings-NZEB

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***Abstract* – The objective of this MSc thesis is:**
- to review and present the techniques and technological instruments that contribute to the reduction of energy consumption so as a building takes a full advantage of its environmental design, in order to support the minimum energy demands covered by Renewable Energy Sources-RES
- to conduct energy and financial evaluation of a suggested, hypothetical building to which the above techniques and technological instruments are applied, so as to examine whether the construction of such building is beneficial from economic point of view to be ranked as a "Zero Energy Building-ZEB or Nearly Zero Energy Building-NZEB".

Keywords: Environmental Design, Energy Design, Bioclimatic Design, Passive Systems, Energetic Systems, Renewable Energy Sources-RES, Financial Evaluation, Cost-Benefit Analysis

I. INTRODUCTION

In the context of dealing global energy issues the recognition of the importance of the building sector participation in the energy balance leads to the design of more energy efficient buildings and the use of Renewable Energy Sources-RES. In this context, we examine the development of sustainable energy buildings. Technology, and, thus, the construction of modern zero or nearly zero (low) energy residential or commercial Buildings has gained an international attention.

The objective of this MSc thesis is to present and pinpoint the techniques and technological instruments which contribute to the reduction of energy consumption so that a building takes a full advantage of the bioclimatic design, in order to support the minimum energetic demand and ensure that the limited amount of energy required is covered by Renewable Energy Sources-RES.

Initially, the national and EU legislation was reviewed related to the energy performance of buildings to clarify the requirements and energy efficiency. Furthermore, published articles are used to assemble a database of alternative techniques and technological instruments related to this modern construction sector. The sources used for compiling the dataset included research articles published in scientific journals and literature sources such as symposium proceedings, technical reports, construction and product manuals, and internet sources. This comprehensive literature review allowed to assemble, present and evaluate the most promising approaches, methodological tools, technical recommendations, and background information, towards improving the capacity to determine current needs, limitations and modern achievements on the field of zero or low-energy building construction.

Old and modern techniques for the reduction of energy consumption are presented along with information on the structural elements of the buildings and the energetic thresholds that any method could reach. A spatiotemporal description of the observed patterns and the evolution in research and development of zero or nearly zero-energy residential or commercial buildings is presented. Emphasis is given on new research achievements that significantly reduce consumption, but further maximize benefits from an environmental based design due to eliminating energy demands and providing energy solutions relying explicitly on RES, and, thus, result in zero or near zero (low) energy buildings.

An energy analysis of a suggested building was conducted, with the use of specific software (TEE-KENAK 1.29.1.19_20_05_12), using the aforementioned techniques and technologies in different combinations in three scenarios.

This MSc thesis concludes with a cost-benefit analysis financially evaluating the three scenarios, based on certain criteria. Those scenarios cover both the energy demands and the financial ones. In order to evaluate whether a Zero Energy Building-ZEB or Nearly Zero Energy Building-NZEB is a beneficial sound investment from the financial point of view, or not.

II. METHODOLOGY

For the needs of this MSc thesis, a roof ground-floor house with basement located in a rather big property, is studied and designed in order to leave room for options concerning the space, building orientation, the benefits of the surrounding space etc. The building dimensions are above the average of a typical Greek detached house, still spacious serving the needs of a four-member family. It is located in the D climatic zone in Greece, being the harshest, in the region of Florina.

Building Elements:

- Town Florina
- Zone D
- Basement Area 190,19 m^2
- Ground-floor Area 179,43 m^2
- Ground-floor Height 3,50 m

- Ground-floor Volume 628,01 m^3
- Windows-Doors Area 38,83 m^2
- Heated Area 167,94 m^2
- Cold Area 83,97 m^2

An analysis of the energy budget, gain and losses of a suggested building is conducted. For the purpose of this analysis, three scenarios that simulate suggested energy reduction techniques are tested within a key-model building. In order to evaluate the energy performance and financial sustainability of the building, the basic land site and construction attributes remained constant, while gradually changing features related to energy efficiency (e.g. insulation, shading, frames, heat mode etc.). In the final scenario, a series of changes were applied resulting in a zero energy building-ZEB. In all three scenarios the study, supervision and construction were done according to the best scientific approach to minimize the case of errors and construction imperfections.

A. Building Design

The 3rd scenario of the building, fully utilizes the potential of the property and the bioclimatic and energy design. These are:

-The building orientation is southern, with most of the windows and doors facing south, having the framing percentage within the assigned limits dictated by the environmental design limits.

-The positioning of the building is the most adequate, since it is linear covering the east-west axis with the biggest percentage of the surfaces facing south.

-The orientation of the building to winds is the best possible, having the lowest exposure to western winds in the winter season. Whereas it benefits from the cooler winds during the warmest months.

-The arrangement of the interior is the best possible.

-The natural lighting to the interior is achieved by the openings in the building and the light tubes in the roof, leading the natural light to the darkest parts of the building, such as the corridor, storage room etc.

-The natural ventilation is achieved by the openings in all the faces of the building. The above passive ventilation system is aided by roof fans during the summer months.

-The way of studying, supervising, constructing and proper placing of external insulation minimizes the possibility of thermal bridges; for the same reasons the air-tightness of the building is the best possible.

-The external insulation is 0,20m thick, achieving an average U=0,137W/m^2·K of the solid elements. The framing is synthetic with Uw=0,78W/m^2·K, with triple energy glasses (4-14-4-14-4) having Ug=0,60W/m^2·K.

-Thermal storage occurs in the construction elements, such as reinforced concrete, marbles, etc, and a centered built fireplace with a chimney, the wall and the floor of the greenhouse and Trombe walls.

-Shading is performed with a pergola with automatic blinds and rolling shutters. This pergola is designed to fully provide shade during summer season, and at the same time, allowing the sun to reach the surfaces of the building during the winter season. The rolling shutters are used as an insulation during the winter nights. Moreover the surrounding vegetation provides shading.

-The heating of the building is provided by a geothermal heating pump (16,00 KW), an energy-efficient fireplace (27,00 KW) in the living-room area which functions supplementarily as the solar panels (18,00 m^2) placed on the roof. All the systems, both energetic and passive, are controlled by the Building Energy Management System-BEMS which also controls the heating system. The BEMS is analysed later on.

-The heated water is provided by the geothermal heating pump and the solar panels during the winter season and only by the solar panels (18,00 m^2) during the summer season.

-The electricity needs are covered by photovoltaic panels on the roof, having 70,00 m^2 surface and 10,00 KW power.

-The passive solar heating system consists of 20,80m^2 glasses of direct solar heating, 18,30 m^2 Trombe walls in the bedrooms and a 15,20 m^2 greenhouse floor adjusted to the living-room for the improvement of thermal efficiency.

-The cooling of the building during the summer season, if needed, is achieved by the geothermal heating pump.

-The tilt of the pointed roof is 30° facing south, so the solar systems do not extrude. The roof insulation is 0,25 m.

-The installed Building Energy Management System-BEMS reduces energy consumption and controls all the above systems including air quality, temperature etc.

B. Thermal Function and Functionality of the Building

The big thermal mass of the building controls overheating during the summer season, as well as the BEMS controls the shading, the passive systems and ventilation from preventing overheating.

The Thermal Function and Functionality of the Building is analyzed as follows:

-During the winter days, the rolling shutters of the windows and the Trombe walls open, while the automatic blinds of the pergola take the right position to allow the collection and storage of solar energy. During the night the rolling shutters close to mitigate any thermal loss-night insulation. At the same time, the Trombe walls and greenhouse ventilation slots/valves close.

-The BEMS facilitates to minimize energy consumption.

-During the summer days, the rolling shutters of the windows open to allow natural light to the space, the automatic blinds of the pergola take the right position to maximize shading of the building, the Trombe walls rolling shutters and ventilation slots/valves remain closed while the glass doors of the greenhouse remain open.

-During the summer nights when the external temperature is lower than the internal temperature the windows, the ventilation pockets of the Trombe walls and green house open so as to cause natural ventilation and cooling.

C. Energy Evaluation

A specific software (TEE-KENAK 1.29) was used for the energy evaluation in the three scenarios.

The 1st scenario building was ranked in the B+ category, with a total primary energy consumption of 108,50 KWh/m^2. The construction, after a rough estimate reached 235.000,00 €.

The 2nd scenario building was ranked in the A+ category, with a total primary energy consumption of 45,00 KWh/m^2. The construction, after a rough estimate reached 280.000,00 €.

The 3rd scenario building was ranked in the A+ category, with a total primary energy consumption of 0,50 KWh/m^2. The construction, after a rough estimate reached 330.000,00 €.

TABLE I
ENERGY RESULTS ACCORDING THE TEE-KENAK 1.29 SOFTWARE

Primary energy by final use-sector (KWh/m^2)				
Final use - Sector	**Reference Model Building**	**1st Scenario Building**	**2nd Scenario Building**	**3rd Scenario Building**
Heating	131,60	93,80	44,00	17,80
Cooling	8,80	0,00	0,00	3,20
Usage of boiled water	36,50	14,70	1,00	1,00
Lighting	0,00	0,00	0,00	0,00
RES contribution	0,00	0,00	0,00	21,50
Total :	176,90	108,50	45,00	0,50
Energy efficiency	1,0000	0,6133	0,2544	0,0028
Energy ranking	B	B+	A+	A+
CO_2 Emissions (tn/year)	7,93	4,81	0,34	0,05

In order to assess the annual energy cost of the building there was a result comparison of every scenario of the above table regarding the reference model building. The annual energy cost of the reference model building was calculated according to the results of the TEE-KENAK 1.29 software, and are: 148,90 KWh/m^2 oil consumption, 4,90 KWh/m^2 electricity consumption and 5,90 KWh/m^2 solar consumption. The cost of oil thermal energy is 0,145 €/KWh including all the charges of the electric company's bill by KWh plus the fixed four-month payment. So, the annual energy cost report is formulated as follows:

179,43 m^2 x 148,90 KWh/m^2 x 0,145 €/KWh = 3.873,98 €
179,43 m^2 x 4,90 KWh/m^2 x 0,11241 €/KWh = 98,83 €
4,80 € x 3 four-months = 14,40 €
3.987,21 €

There are tables for the calculation of the annual energy cost of each scenario regarding the annual energy cost of the reference model building. The table below shows the percentage of energy improvement, the estimated benefit by m^2, the estimated cost, as well as the annual estimated benefit and cost of the 3rd scenario building.

TABLE II
ANNUAL ENERGY COST AND BENEFIT OF THE 3RD SCENARIO BUILDING

Primary energy consumption by final use-sector (KWh/m^2) of **3rd Scenario Building**			
Final use - Sector	**Reference Model Building**	**3rd Scenario Building**	**Percentage Improvement**
Heating	131,60	17,80	86,47 %
Cooling	8,80	3,20	63,64 %
Usage of boiled water	36,50	1,00	97,26 %
Lighting	0,00	0,00	0,00%
RES contribution	0,00	21,50	- %
Total :	**176,90**	**0,50**	**99,72 %**
Annual energy cost	3.987,21	11,16	99,72 %
Cost per m^2 of building	22,22	0,062	
Benefit per m^2 of building		22,158	
Annual energy cost reduction (benefit)		3.976,05	

D. *Financial Evaluation and Cost-Benefit Analysis*

For the evaluation of the financial sustainability of Zero Energy Building-ZEB or Nearly Zero Energy Building-NZEB a cost-benefit analysis was conducted. This analysis facilitates the comparison of alternative scenarios by comparing the relevant expenditure and revenues of each scenario. Those scenarios are financially compared by employing certain criteria. To avoid any misleading results and false conclusions, each criteria must be calculated regarding the present and future values, so as to have a common base for comparison.

To financially evaluate the project, certain data must determine:

-The sustainability of the project/investment. The recommended duration of the energy project including residential projects which is 20 years.

-The overall cost of the project includes the initial cost, operating cost and maintenance cost. In the initial cost were included only those elements which contribute to energy evaluation, such as insulation cost, framing, heating system, sunproof systems, control systems, automations etc, and their cost changes from scenario to scenario affecting the cost of the project. While elements which remain the same were ignored, such as the excavation cost, reinforced concrete cost, wall building cost plumbing cost etc. The operating cost for the first year is calculated in the above tables as annual cost, increasing every year by certain percentage which represents the average energy cost increase. Finally, the annual maintenance cost, which is the cost of the regular maintenance of every element of the project, was approximately estimated based on tables and data in the market.

-The benefits deriving from the project/investment. Due to the nature of the project there are not specific revenues but benefits from the reduction in energy consumption. Benefit is considered the annual reduction in energy cost. In the 3rd Scenario the photovoltaic installation covers the energy needs of the building and the remaining output is sold.

After the determination and assessment of revenues and benefits the net cash flows are calculated for the assigned time period in which the project is evaluated, subtracting annually from the total revenues the total expenditure. The net cash flows means profit, where the revenues is bigger than the expenditure-cash inflows, while the negative net cash flows means loss-cash outflows. The net cash flows occur in different time-periods; thus, can not be dealt equally. For that reason, any future net cash flows should be converted into present values so as to be comparable.

One of the conventional and suggested methods of evaluating the cost and benefits of a project/investment is the calculation of the Net Present Value–NPV. Other criteria are the Internal Rate of Return–IRR, The Benefit – Cost Ratio, also known as Present Value Ratio and the Payback Period.

III. SELECTED RESULTS

Using the above criteria Tables were made for each of the three scenarios with their financial evaluation. Table III has the concentrated results from the tables of each scenario.

TABLE III
CONCENTRATED TABLE OF ENERGY AND FINANCIAL EVALUATION

	1st Scenario Building	**2nd Scenario Building**	**3rd Scenario Building**
Total primary energy consumption	108,50	45,00	0,50
Initial Project Cost	56.980,00	104.610,00	146.107,50
Annual energy cost (for the first year)	2.445,36	1.014,35	11,16
Annual energy cost reduction (benefit for the first year)	1.541,85	2.972,86	3.976,05
Net Present Value – NPV	-98.969,28	-123.131,94	-111.414,31
Internal Rate of Return – IRR	-	-0,06	0,02
Benefit – Cost Ratio	0,25	0,39	0,68
Payback Period	70,51	75,81	30,47

Concerning the financial evaluation, the three scenarios indicate that if the project/house is seen as an investment, according to the above mentioned criteria, should be rejected as financially not viable. This outcome is reasonable since residential building does not bring revenue to the owner. Nonetheless, comparing the financial criteria, the best solution is that of the 3rd scenario. Even in the Net Present Value – NPV, although it seems clear in raw numbers that the 1st scenario is the most preferable, in comparison with the initial cost the 3rd scenario has cost reduction regarding the 20-year sustainability time period.

The combination of the suggested techniques and technological instruments minimize the energy consumption of the building, the use of conventional fuel reducing gas emissions turning it into a highly energy efficient building oriented to the use of Renewable Energy Sources-RES. The reduction of energy consumption led the 3rd scenario building to be ranked in the Zero Energy Building – ZEB or Nearly Zero Energy Building-NZEB category.

IV. CONCLUSIONS

The results of the cost-benefit analysis demonstrate that although the cost of construction of a zero or near zero (low) energy consumption building is comparatively higher, it represents a very wise decision due to the long-term economic gains, and the environmental and social benefits that are raised from such a sustainable solution. In addition, the fact that such choice is usually characterized by favorable indoor conditions, higher aesthetic value, and resale value, as well as giving the sense to the residents of personally and directly contributing to energy saving provides further support to the arguments towards green and energy efficient constructions.

The above provide the conclusion that Greece is at a transitional phase concerning the energy status in the building sector and there is great room for improvement in energy saving. The use of fossil fuel is possible to be reduced significantly. The proposed measures for energy saving can be the turning point in energy use in the building sector. There are also conclusions about the minimization or even elimination of energy consumption as for the present building design, based on the Building Energy Performance Regulations in Greece and the way future building design should be implemented, effective as from December 31, 2020.

REFERENCES

ASHRAE handbook fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2009.

Dunnett Ni., Kingsbury No. (2008), *Green Roofs and Facades*, Psihallou, Athens.

Gauzin-Muller D. (2007), *Ecological Houses*, Modern Architecture, KTIRIO, Thessaloniki.

Goulding J., Lewis O., Steemers T. (1994), *Energy Design – Introduction for Architects*, Malliaris Pedia for the European Commission, Thessaloniki.

Kachadotian J. (1997), *The Passive Solar House*, Using Solar Design to Heat and Cool your Home, Canada.

Torcellini P., Pless S., Deru M. (2006), *Zero Energy Buildings: A Critical Look at the Definition*, NREL, California.

U.S. Green Bulding Council, LEED (Leadership in Energy and Environmental Design), Reference Guide version 2.0, 2001.

Amourgis S., Kosmaki P., Loukopoulos D., Strousopoulos E. (2004), *Environmental Design for Cities and Urban Open Spaces*, Volume B, Ecological Design Principles, H.O.U., Patra.

Axarli K., Giannas S., Evaggelinos E., Zaharopoulos I., Marda N. (2001), *Bioclimatic Design of Buildings and Surrounding Area*, Volume A, Bioclimatic Design of Buildings, H.O.U., Patra.

Axarli K., Papadopoulos M. (2011), *Energy Design and Passive Solar Building Systems*, Publishing House of Brothers Kyriakidi S.A., Thessaloniki.

Aravantinos D. (2009), *Thermal Bridges in Buildings, The Weaknesses of the Outer Shell*, KTIRIO, Monthly Magazine, Issue 10, pages 117 – 141.

Aravantinos D. (2009), *Building Interventions for the Prevention of Thermal Bridges*, Seminar " Energy Design of New and Existing Buildings ", T.C.G. – D.C.M. Education Sector, Thessaloniki.

Aravantinos D. (2011), *Control of Thermal Insulation Adequacy Building*, Seminar "Energy Study Pension Under the K.EN.A.K", T.C.G. – D.W.M. Education Sector, Florina.

Aravantinos D. (2011), *Energy Design Guide, Bioclimatic Architecture and Energy Saving*, KTIRIO, Thessaloniki.

Georgiadou El., Andreadaki – Hronaki E., Zisis Xen. (1996), *Bioclimatic Design*, Clean Technologies Building, Paratiritis, Thessaloniki.

Theodosiou Th. (2012), *Energy Building Design*, Notes for the course "Energy Planning and Development of Solar Energy in Construction", School of Civil Engineering, A.U.TH., Thessaloniki.

C.R.E.S. (2002), *Bioclimatic Design in Greece: Energy Efficiency and Implementation Guidelines*, Athens.

C.R.E.S. (2003), *Solar Thermal Systems*, Students Guide, Athens.

Kakaras Em., Karellas S., Vourliotis Pan., Grammelis Pan., Pallis Pl., Karampinis Em. (2013), *Heating Cost Comparison of Various Technologies*, Steam engines and boilers Laboratory, School of Mechanical Engineering, N.T.U.A., Athens.

Korma Ef. (2004), *Solar Conditioning Guide*, C.R.E.S., Athens.

Kosmopoulos Pan. (2007), *Environmental Design*, Second Enhanced Version, University Studio Press, Thessaloniki.

Kosmopoulos Pan. (2012), *Energy We and Our Buildings*, $ECON^3$, Bimonthly Magazine, Issue 22, pages 80 – 86.

Kosmopoulos Pan. (επιμ.) (2008), *Buildings, Energy and Environment*, University Studio Press, Thessaloniki.

Kostantinidou Chr. (2009), *Bioclimatic Architecture & Energy Planning* , TeKΔOTIKH, Athens.

Meresi Cath. (2010), *Saving Energy in the Classroom Through Natural Lighting*, Doctoral thesis, School of Architecture, A.U.TH., Thessaloniki.

Papadopoulos Ag. (2006), *Thermal Comfort in Buildings, New Standards and Improving Thermal Comfort in Buildings*, School of Mechanical Engineering, A.U.TH., Ioannina.

Perdios St. (2009), *solar thermal installations*, TeKΔOTIKH, Athens.

Stasinopoulos Th. (2001), *Insolation Control*, Notes for the postgraduate course "Bioclimatic Design", School of Architecture, N.T.U.A., Athens.

T.C.G. (2010), T.D.T.C.G. 20701-2/2010, *Thermophysical Properties of Building Materials and Proficiency Control of Thermal Insulation of Buildings*, M.E.E., Athens.

T.C.G. (2011), T.D.T.C.G. 20701-5/2010, *Bioclimatic Design of Buildings*, M.E.E., Athens.

T.C.G. (2011), *Adequate Insulating of Building Shell*, Energy Inspectors Training - Training Material, A. Building Inspection, Topic DK2, Athens.

T.C.G. (2011), *Climate and Interior Environment. Bioclimatic Design of Buildings*, Energy Inspectors Training - Training Material, A. Building Inspection, Topic DE3, Athens.

T.C.G. (2011), *Τεχνολογίες Ανανεώσιμων Πηγών Ενέργειας*, Energy Inspectors Training - Training Material, A. Building Inspection, Topic DE4, Athens.

Tsigas Er. (1996), *Energy in Architecture - The European Manual for Passive Solar Buildings*, Malliaris Paideia for the European Commission, Thessaloniki.

Tsikaloudaki K. (2010), *Energy Performance of Buildings and Architectural Design*, Presentation for the course "Special Topics in Building", School of Civil Engineering, A.U.TH., Thessaloniki.

Tsikaloudaki K. (2010), *The Thermal Efficiency of the Building Shell*, Presentation for the course "Special Topics in Building", School of Civil Engineering, A.U.TH., Thessaloniki.

Tsikaloudaki K. (2010), *Natural Daylight in Buildings*, Notes for the course "Special Topics in Building", School of Civil Engineering, A.U.TH., Thessaloniki.