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A STUDY OF SENSOR NETWORKS AND AUTOMATION APPLICATIONS FOR ENERGY SAVING OF BUILDINGS

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***Abstract*— The continuous affluence in consumer goods, overall improvement of the living standard as well as the excess growth in population has led to the rapid increase in energy consumption over the last twenty years. Buildings in large Greek urban centres affect the environment adversely, causing a variety of problems; architects, in effect, have sought new ways of environmentally friendlier residence construction. As a result there has been a turn towards Bioclimatic Architecture, implementing renewable energy Sources and energy saving techniques. The main body of this study explains the criteria for the design of a bioclimatic residence, the sensors, mechanisms as well as environmental factors that affect the transformation. Furthermore, the study designs a program for the calculation of transformation costs.**

***Keywords*—Sensoring, bioclimatic residence, renewable energy sources, energy saving**

I. INTRODUCTION

Buildings and environment are mutually affected during all phases of building construction, function and demolition. Thus for the correct design of buildings full knowledge of this interaction is required. The actual energy demands of buildings in Europe are covered to a large extent by the indirect usage of solar radiation as well as other atmospheric resources.

Architects have turned towards finding new ways of residential construction that are healthier and friendlier to the environment. As a result there has been a turn towards Bioclimatic Architecture that implements renewable energy sources and energy saving techniques. Bioclimatic Design aims at the capitalization of positive environmental parameters in order to reduce the building's energy demands year-round and save conventional energy. Bioclimatic Architecture is mainly the result of an integrated and complex composition that is connected to a large spectrum of parameters, such as the orientation, the proper choice of building openings, the study of the shell as well as the proper choice of materials. This doesn't mean, however, that there can only be limited interventions on already existing buildings. Implementing user friendly technologies at a low cost can help reduce heat losses, protect buildings from overheating, improve lighting conditions and reduce noise. All of the above are connected to Bioclimatic Design and contribute to the development of construction that covers the demands of contemporary lifestyles without posing a threat to future generations. The construction of a passive solar residence, as it is called, should be preceded by a study of climate, topography, solar position and plot inclination, so that the researcher can gather the necessary data in order to proceed to its design. Knowledge of the aforementioned parameters will lead to the correct placing of the building on the plot, and also to the correct assignment of shape and orientation in accordance to the conditions of the surrounding area and environmental elements, thus ensuring the maximum amount of energy saving.

Bioclimatic architecture is the type of architecture that leads to the construction of buildings able to save energy in the form of heating, cooling and lighting. This type of architecture refers to the design of buildings and spaces (indoors and outdoors) based on the local climate, usually referred to as microclimate. It aims at ensuring comfortable temperature and lighting conditions by exploiting solar energy and other environmental sources, including natural climatic phenomena. "The basic elements of bioclimatic design are passive systems integrated in buildings in order to utilize environmental sources for heating, cooling and lighting."

II. DESCRIPTION OF THE PROBLEM

The actual energy demands of buildings in Europe are covered to a large extent by the indirect usage of solar radiation as well as other atmospheric resources. Fuel distribution currently amounts to: 43% various types of fuel for the production of electrical energy, 20% direct petroleum usage, 18% natural gas usage, 6% other solid fuels and 15% solar energy. Based on these figures, energy demands in European buildings amount annually to one ton of petroleum per inhabitant. The tendency is slightly growing over the last years and the annual increase in the rate of consumption in buildings equals 0.7%.

Suburban sprawl exacerbates the problem, degrading both urban and rural settings by causing forest fires and replenishing local fauna and flora. Finally, the usage of radioactive and non-ecological building materials is directly responsible for public health issues as well as the degradation of the living standard, via the inhalation of toxic substances. The aforementioned problems have led architects into implementing new ways of healthier and environmentally friendlier building construction. As a result there has been a turn towards Bioclimatic Architecture and the implementation of renewable energy sources and energy saving techniques that can lead to the progressive reduction of the environmental crisis and to the upgrade of the urban environment [1].

III. SYSTEM DESCRIPTION

1. General Information

Bioclimatic Design aims towards the capitalization of positive environmental parameters in order to reduce a building's energy demands year-round and save conventional energy. Bioclimatic Architecture is mainly the result of an integrated and complex composition, connected to a large spectrum of parameters, such as the orientation, the proper choice for building openings, the study of the shell as well as the proper choice of materials. This doesn't mean, however, that there can only be limited interventions on already existing buildings. Implementing user friendly technologies at a low cost can help reduce heat losses, protect buildings from overheating, improve lighting conditions and reduce noise. All of the above are connected to Bioclimatic Design and contribute to construction development that covers the demands of contemporary lifestyles without posing a threat to future generations. Construction of a passive solar residence, as it is called, should be preceded by a study of the climate, topography, solar position and plot inclination, so that the researcher can gather the necessary data in order to proceed to its design. Knowing all that, the researcher can place the building correctly on the plot, assigning it a proper shape and orientation in accordance to the conditions of the surrounding area as well as environmental elements, thus ensuring the maximum amount of energy saving. Another core element is building materials, which should be environmentally friendly, recyclable and non-damaging to human health. It is important that the building skeleton is solid and that it possesses large thermal mass and good heat insulation. A characteristic of bioclimatic residencies is the fortification of thermal mass and heat insulation with the maximum usage of ecological construction materials, resulting in the preservation of a steady indoors temperature and fairly low levels of humidity.

2. Usage of Renewable Energy Sources

Bioclimatic design implements renewable energy sources mostly in the form of solar and wind power, as well asgeothermal power (biomass and biogas), by means of photovoltaic panels (converting solar to electrical energy), district heating systems (using biomass ducts in order to produce and provide residencies with hot running water and heating), composting of solid waste for the production of biogas and finally, geothermal systems of heating and cooling.

3. Planting interventions and landscaping

Vegetation is an important characteristic of bioclimatic architecture, as it contributes to the climatological conditions of open spaces. Vegetation prevents overheating by ensuring natural air flow, and also contributes its shading and cooling properties. When placed correctly it also retains flowing air particles, protecting from dangerous emissions. Due to the plants' ability to retain rainwater, vegetation also contributes to better drainage and prevents ground corrosion. Finally, it contributes to energy saving due to its ability to control temperature by providing sun protection in the summer and wind protection in the winter.

4. Phases of a bioclimatic study

The procedure of a bioclimatic study is divided in five phases. The first phase includes the proper topographic map, the study of the subsoil by means of a geological map, the assessment of electromagnetic activity levels that can be emitted by cell phone antennas, electricity pillars and cables, and other; the study of existing vegetation as well as the surrounding terrain. Finally, the estimation of the position of the sun is made with Solar Pathfinder. The second phase includes the study of the climate, thermal comfort and solar geometry. The third phase includes building scheduling. The fourth phase is the study of passive solar systems in order to save energy for heating and cooling, and also the study for sunlight, shade and natural light. During that phase it is possible to investigate the ways by which a building can become autonomous energy-wise with the usage of photovoltaic units or wind turbines, and also the usage of building materials, and the alleviation of negative health effects from other materials such as reinforced concrete – finally, to determine a building's energy identity. The implementation study occurs during the fifth phase.

5. Bioclimatic design of a building

Bioclimatic architecture is defined as the design process whereby a researcher takes into account a number of parameters aiming at rational energy use and the saving of energy. Parameters taken into account are the local climate (solar energy can provide thermal and visual comfort), various natural phenomena as well as other environmental parameters such as sunshine, vegetation, wind, relative humidity, outdoors wind temperature and finally, shading by adjacent buildings. The main elements of bioclimatic design are passive systems implemented in buildings aiming at exploiting the environmental resources available for the purpose of heating, cooling and natural lighting.

Figure 3.5 Implementation of bioclimatic architecture in a residence

3.6 Functional organization of indoor spaces

During the phase of indoor design there needs to be organizing and grouping so that the most frequently used spaces are placed on the southern side of the building. The purpose of this design is to acquire the highest indoor temperatures, as is usually desired. Spaces that are less used, in contrast, and thereby have lower temperature demands, should be placed in the intermediate thermal zones. The remaining spaces, usually used for storage, are preferably placed on the northern side of the building so that they protect and insulate the rest of the residence by separating the outdoor from the warmer indoor environments. This way, thermal losses can be reduced in the main residential spaces. A room designed on the east-west axis should allow all residential rooms to be facing south. However, this form is not always desirable. For detached residencies, a moderately lengthened design can ensure that most rooms are facing south. In order to minimize the disadvantage in northern oriented rooms, a few windows can be placed on the western or eastern wall.

6. Building Form

The "building form" is important energy-wise as it relates to its thermal behaviour; the shell of a building filters thermal interaction with the environment. During this design phase the researcher is called to a choice between an "open" and a "closed" building form, i.e. aggressive or defensive. A building with large openings is called open whereas small openings define a closed building. The proper choice of openings is determined by certain criteria such as the local climate, building orientation, the view, security, noise, the cost of construction, and so on. Energy-wise both types of building forms can lead to similar results under different circumstances. An open form is preferred for a southern oriented building that is not shaded by nearby building, trees or other obstacles. Thus the advantages of solar energy are maximized by implementing certain modifications; passive solar systems or building openings result into immediate solar gains. For buildings that are not facing south it is preferable to use a closed building form, its main characteristic being small openings and fortified insulation of building materials in order to minimize thermal losses, as well as the appropriate sun protection. The definition of "form" may also include the building mass configuration. A number of alternative suggestions can be taken into account when examining an existing building or surface outline any of those spaces, however, will exhibit a separate thermal behaviour since their outer surfaces are differentiated in size and temperature.

7. Size of openings

Openings' size in accordance to building orientation can be a determining factor to the building's function as a solar collector. The basic material used for openings is glass, not a particularly insulating material, heat-wise, thus resulting into major thermal losses from glass panels. However, glass panels can also be responsible for thermal gains provided that the building is oriented towards the South with an angular tolerance of ±30˚east or west. Therefore, large openings are recommended, single or double glazed, when facing the South, mid-sized openings when facing the East and the West, whereas northern windows should be smaller and double-glazed. All this could change if there is a view to the North. If south-facing openings are double-glazed, solar gains outgain thermal losses by a 23% during the winter period. Double-glazed openings that also have blinds will yield an even larger thermal gain of 56%. Finally, in order for the southern opening to function as a solar collector, it should be fortified by double-glazed glass, insulated blinds and the proper placement of window frames.

8. Thermal capacity of building materials

Thermal capacity is a measure that indicates the level of energy required in order to raise the temperature of a material, equal to the ratio of the heat added to (or removed from) an object to the resulting temperature change. As a rule, the higher the material density, the higher its thermal capacity. Therefore, buildings constructed with materials of high thermal capacity are referred to as heavyweight structures, versus lightweight structures where materials of low thermal capacity have been used. Typically a building holding a wooden frame will hold a low thermal capacity whereas a building holding a frame of reinforced concrete will have a high thermal capacity.

9. Heat insulation

A central element for the proper function of a passive solar residence is heat insulation. The combination of building materials, the installation as well as the meticulousness of the installation process will have a long term effect on the building's natural function, the residents' health and finally the energy bills. The heat insulation standard will significantly impact thermal performance, design and function of heating systems as well as the fuelling needs and comfort of the residents.

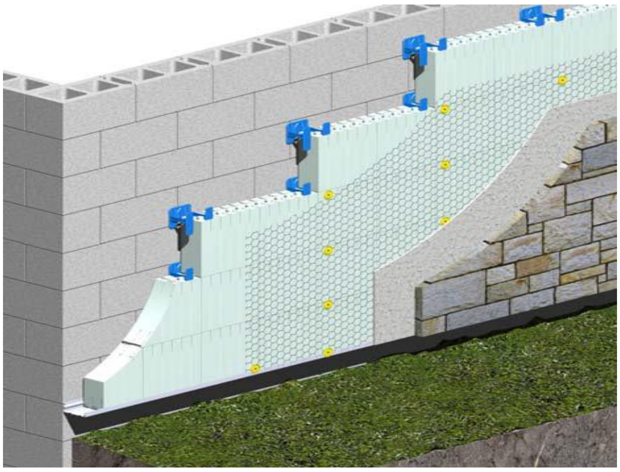

Fig. 1. Heat Insulation in Walls

10. Shading

Shading of the building and its openings can be achieved by planting deciduous trees and vegetation in a manner that ensures that sunlight is filtered during the summer period thus reducing the outdoors temperature due to the ability of the foliage to absorb heat. The sun protection for openings as well as the appropriate size, form and position of the shading system depends on the orientation of the façade. Shading is necessary for openings located on the outer side of the building in order to avoid sunlight penetration and indoor overheating. The placement of blinds on the inside of glass panels reduces glare from intense sunlight but fails to protect the building from overheating as the glass has the property of capturing sunlight and transforming it into heat. The basic criteria for choosing the best system for sun protection of openings is the orientation of the façade, the aesthetic factor as well as the morphology of the openings, i.e. continuous versus separated by walls, and most importantly, the building function; residence, work space, or other. Last but not least, the financial factor, including the cost of construction as an initial investment as well as the long lasting cost of operation.

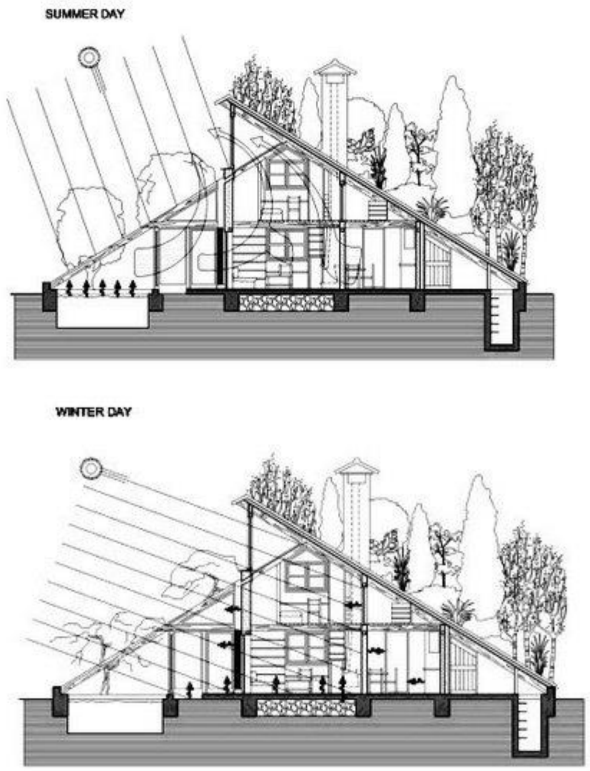

Fig. 2. Shading Measurements

11. Building Ventilation

The construction of an airtight shell that can control and restrict the indoor circulation of air is extremely important for the prevention of general heat loss as well as heat leakage from the window joints, depending on the building function and the international standards for hourly air change rate. Unnecessary, uncontrollable and extensive ventilation has a negative effect on the building's energy balance as it largely increases its heating needs. Research has shown an aggravating tendency of this phenomenon as a result of the demand for high indoor temperatures combined with a low quality heating system, usually due to inadequate maintenance. The continuous renewal of indoor air is very important for human health as well as the prevention of mold, bad odors and emissions.

Fig. 3. Building Ventilation Schematics

IV. WEB APPLICATION FOR ONLINE COMPUTATION

This chapter presents the algorithm as well as the procedure of the cost calculator for the transformation of a bioclimatic residence, based on user-defined parameters. The rise of the internet over the last decades offers strong opportunities for the promotion of a research idea as well as the simplification of the calculation procedures required for its implementation. The development of applications such as databases, context-enriched services and geographical signs make it possible for a layperson to gather the necessary data for transforming a conventional residence into a bioclimatic one. At the same time, a researcher can store said data in order to enrich one's clientele and also to derive useful statistics.

1. Application development

The necessary data for the development of an online application are, first and foremost, the database where user input is stored, and secondly, context-enriched websites that the user views and interacts with.

For the purpose of developing an application for the transformation of a conventional residence into a bioclimatic one, the websites used possessed the following structure:

- Welcome page
- Data input page
- Calculation page
- Results page

The development of the actual application implements the PHP programming language, which, in collaboration with the SQL database, can extract user data and store it on the database for later processing and presentation, when needed.

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Welcome page: The welcome page is the "storefront" of the application; it should be modern, simple and understandable to the layperson. Information presented in this page is basic, aiming at preparing the user for the following page.

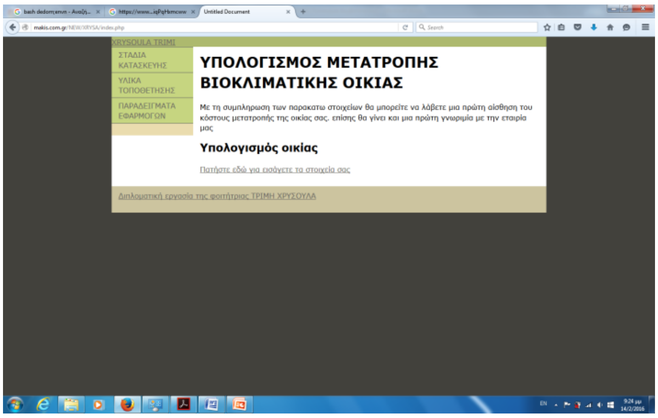

Fig. 4. The Welcome Page of the WEB Application

Data input page: In this page the user enters the data needed for processing as well as personal data for the purpose of possible future contact. It is important in this stage to properly guide the user into entering the data correctly.

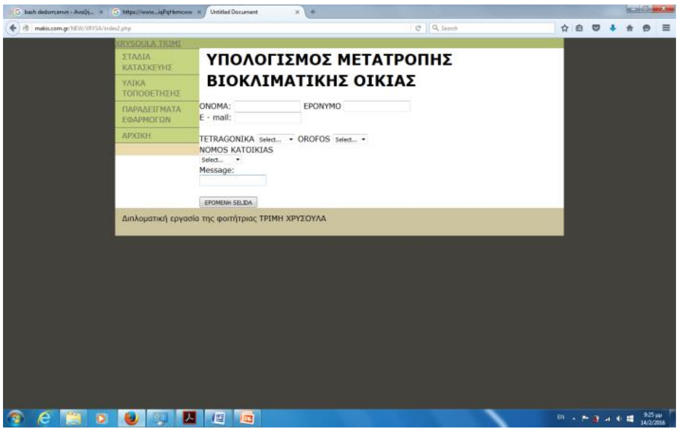

Fig. 5. The Data Input Page of the WEB Application

Calculation page: This page is hidden to the user, but essential to the researcher. In this stage several procedures take place; calculation of the transformation stages, input of geographical and constructional parameters, and storage in the database for further use on demand.

Results page: This page presents the calculation results made by the application, thus offering the user an idea of the theoretical cost for the transformation of said residence. It is extremely important to clarify that the calculation of costs is correct but it is also relevant, as each transformation constitutes a special case, and that the user should not rely entirely on this particular offer.

Database: A database is a tool for the collection and organization of information. Databases can store information about people, products and orders and just about anything else. Lots of databases start as simple lists made with a word processor or spreadsheet. As the list grows, more and more inaccuracies and repetitions occur. Understanding this data in the form of a simple list becomes progressively more difficult; also there are very limited ways for data searching or the output of subtotals for further review.

In the presented application, the spreadsheet stores general interest data such as user name, surname, e-mail and geographical data concerning the property such as district, floor, area in square meters and age of the building.

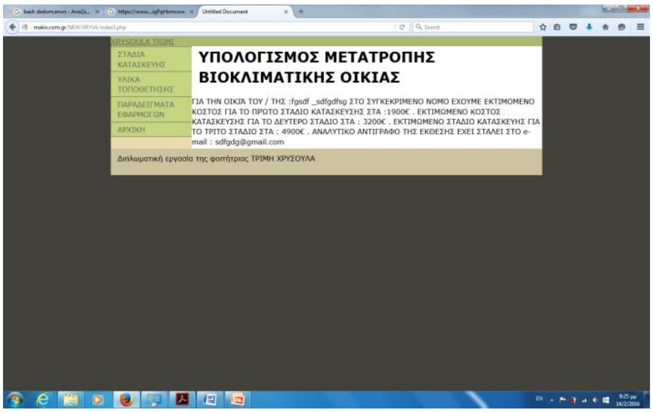

Fig. 6. The Algorithm Outcome of the WEB Application

Calculation analysis: The procedure of transforming a conventional residence into a bioclimatic one includes several stages that potentially affect the cost of the overall transformation. For the needs of this application, the bioclimatic transformation was divided into three independent stages that can be implemented one at a time. During the first stage, a solar heater is installed in the residence and the old window frames are replaced with insulated glass panels. A necessary parameter for the calculation of transformation costs is the size of the property area; more square meters equal more window frames and a larger solar heater. The second stage calculates the installation cost of external wall insulation for the purpose of achieving the optimal heat insulation of the residence as well as the insulation of other external spaces such as rooftops and inner courtyards. The parameters that affect the cost in this stage are, firstly, the geographical district of the property (affecting the cost of external insulation), as well as the floor where the property lies on (affecting construction expenses). Lastly, in the third stage of transformation, contemporary methods for energy saving are calculated; e.g. the implementation of heat pumps and other automation systems – such as artificial sunlight or shading for the purpose of maintaining temperature at desired levels.

V. CONCLUSION

It is nowadays known that buildings are responsible for the consumption of large amounts of conventional energy, resulting into emissions that are harmful for the environment. Bioclimatic design of buildings helps in deterring the above and also contributes to human health. Benefits of bioclimatic architecture can be summarized in: energy-related (energy saving and thermal/visual comfort), financial (reduced need of costly electromechanical installations), environmental (reduced pollutants and CO2 emissions) and social (improved quality of life).

Potential disadvantages of Bioclimatic Design exist only in the case of an improper study and implementation of the principles of Bioclimatic Architecture. Therefore, in order to achieve the successful performance of bioclimatic residence construction, the necessary prerequisites are the proper design and choice of techniques, the correct implementation of the systems during construction, the appropriate usage and function of the building and last but not least, adequate maintenance.

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