Bioclimatic Design, Evaluation of Energy Behavior and Energy-Saving Interventions at the Theagenio Cancer Hospital

Emmanouel Koumoulas, Aikaterini Rokkou, Marios Moschakis

***Abstract*—**Theagenio" in Thessaloniki exists and works for three centuries now as a hospital. Since 1975, it has been operating as an Integrated Special Cancer Hospital and since 1985 it has been integrated into the National Health System. "Theagenio" Cancer Hospital is located at the central web of Thessaloniki residential complex and consists of two buildings, the "Symeonidio Research Center", which was completed in 1962 and the Nursing Ward, a project that was later completed in 1975. This paper examines the design of the Hospital Unit according to the requirements of the energy design of buildings. Initially, the energy characteristics of the Hospital are recorded, followed by a detailed presentation of the electromechanical installations. After the existing situation has been captured and with the help of the software TEE-KENAK, different scenarios for the energy upgrading of the buildings have been studied. Proposals for upgrading concern both the shell, e.g. installation of external thermal insulation, replacement of frames, addition of shading systems, etc. as well as electromechanical installations, e.g. use of ceiling fans, improvements in heating and cooling systems, interventions in lighting, etc. The simulation calculates the future energy status of the buildings and presents the economic benefits of the proposed interventions with reference to the environmental profits that arise.

***Keywords*—**Energy consumption in hospitals, energy saving interventions, energy upgrading, hospital facilities.

I. Introduction

ENERGY consumption in Greece from 2000 to 2007 has been on a steadily rising trend, following the country's corresponding economic growth. The highest growth rate was recorded by the services sector. Since 2007, the economic downturn has led to a reduction in final consumption of around 30% in all final sectors. The industrial sector is the one that was directly affected at that time. The big decrease in consumption in the transport sector took place a little later and more specifically from 2009 onwards [1].

The domestic sector experienced a significant reduction in energy consumption over the period 2007-2010. This is mainly due to the application of thermal insulation techniques to buildings in order to reduce energy consumption for heating. However, the amounts of energy consumed in buildings remain high, and their reduction is a priority for the European Union as expressed by relevant directives calling for the construction of near-zero-energy buildings by 2020 [2].

The building sector is emerging as a major energy consumer in developed countries due to increased energy requirements for indoor microclimate management, increased use of appliances in buildings, and the transformation of these countries' economies into service economies.

Buildings account for almost 40% of the country's total energy consumption, which makes them particularly energy-intensive [3].

Hospital facilities are a special category of building installation and, at the same time, one of the most energy-intensive installation classes due to the special loads that they manage. Hospitals are the largest energy consumer per area unit in the buildings sector. The large amount of energy consumption observed in hospitals is due to the 24th requirement for heating, cooling, air conditioning and hot water as well as the large and special equipment used in them [4].

There is a need to study the ways of energy saving measures, which will not reduce the functionality of the premises, but instead they will optimize the conditions of stay in the space for both patients and workers.

The bioclimatic architecture concerns the design of buildings and spaces, both indoor and outdoor, based on the local climate. Its purpose is to provide thermal and visual comfort, utilizing solar energy and other renewable sources as well as the natural phenomena of the climate. The goals of bioclimatic design are the non-dependence on fossil fuels, the money saving, the protection of the environment, and the improvement of internal conditions [5], [6].

The energy consumed in buildings is either electrical or thermal. In the other words, energy is used for heating the space during the winter, by burning, usually, oil or natural gas in a boiler and for the consumption of electricity for cooling or heating the building with air conditioners, for lighting, for mechanical ventilation and for the operation of electrical appliances. Thus, the energy class of a building is evaluated according to the final consumed heat and electricity.

In 2002, the European Community Directive 91 on "Energy Performance of Buildings" was adopted, which gave the EU Member States general guidelines to restrict energy consumption in buildings. In April 2010, the Energy Efficiency Regulation of Buildings and in 2017 the revised Regulation were adopted defining the minimum requirements and specifications for all new and radically renovated

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buildings. According to these Regulations, in the energy study, the new or radically renovated buildings should be classified as energy class B or better [7].

Green@Hospital is one of the four initiatives of the 2020 Hospital movement. The project aims to save energy at 15-20% in hospitals by means of innovative scientific techniques and specialized technological applications. Energy savings consist of implementing an intelligent system that monitors the energy consumption of the hospital on a 24-hour basis and performs actions to optimize the operation of its energy systems such as heating, cooling, hot water, ventilation, lighting, etc. [8].

In public buildings, where energy consumption is greater than the residential ones, saving measures that can be applied are the external insulation and the installation of double windows, the installation of shading systems, the use of automation systems for controlling with increased efficiency, the replacement of incandescent lamps with led or fluorescent economy lamps, the use of motion detectors and daylight sensors, the maintenance of heat generation systems (boilers), cooling and finally the production of domestic hot water by solar panels.

II. The Theagenio Hospital Building

The Anti-Cancer Hospital of Thessaloniki is at the center of the city's building fabric. Its facilities occupy an entire building block of 5434.15 m^2 of land. The hospital is divided into three wings. The first wing (A) is the building of the Anti-Cancer Institute (Symeonideion Building). It is a two-storey building with a basement and a roof. The Nursing building is divided into two wings in the B wing (west) adjoining the Symeonidis building and the 3rd wing (east). The building consists of eleven floors and two basements. It belongs to the tertiary sector, in climatic zone C and its use is treated like health and welfare services [9]. The building is shown at Fig. 1.

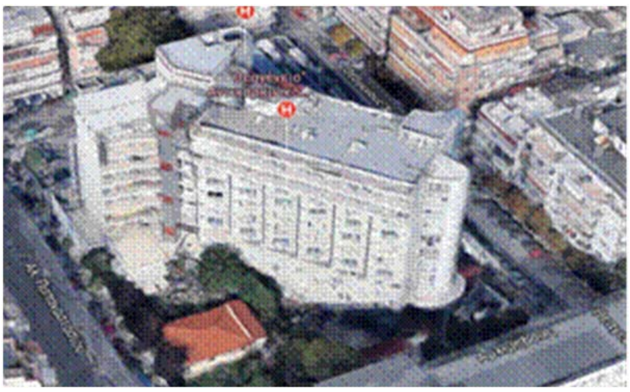

Fig. 1 The Theageneio Anti - Cancer Hospital of Thessaloniki today, east and south view

The hospital's premises include clinics, workshops, offices, warehouses, waiting rooms, patient rooms, reception, technical service, an amphitheater with 210 seats, an emergency room, a kitchen, a shelter, various auxiliary spaces, car parking and all electromechanical equipment such as the medium and low voltage electric substation, the boiler room, the diagnostic machines, the pumping station, three generating sets, the vacuum pump installations and the compressors of medical air [10].

III. Collected Energy Consumption Data

Hospitals in their majority are operating seven days a week and 24 hours a day, while they are special facilities due to the particular conditions prevailing inside them as well as the special loads that they have to manage. The energy consumption intended to meet the thermal needs is composed of individual loads such as heating, hot water, thermal load for the kitchen, washing machine, sterilization, disinfection, etc. The energy consumption intended to meet the electrical requirements, consists of electrical loads such as lighting, air conditioning, lifts, fixed medical equipment, portable medical equipment, computer electrical supplies, electric charge for the kitchen and electric charge for laundry [11].

From the electricity bills of the last four years and with the help of the following table and diagram, we can draw conclusions about the amount of electricity consumption in the hospital.

In Table I and Fig. 2, the consumed electricity (kWh) of the Hospital is presented for the period 2013-2016. It can be seen that the consumption profile remains almost constant per year, and the small differences observed in each year are mainly due to the different climatic conditions of each year. There is also a significant increase in consumption in the summer months, naturally due to the increased cooling needs, which is covered by approximately 330 air conditioners (split type) at the hospital's premises.

TABLE I
Electricity Consumption (KWh) Figures from the Accounts of D.E.I. for the Years 2103-2016

Month \ Year	2013	2014	2015	2016	*Average*
Jan	234 000	224 075	222 116	229 596	*227 447*
Feb	198 000	203 041	198 936	213 798	*203 444*
Mar	210 000	205 558	214 322	237 365	*216 811*
Apr	207 000	204 230	206 915	222 971	*210 279*
May	243 000	244 235	236 819	239 426	*240 870*
Jun	291 000	298 952	266 817	322 584	*294 838*
Jul	348 000	367 888	376 306	372 728	*366 231*
Aug	378 000	377 380	364 320	354 085	*368 446*
Sep	276 000	276 408	295 548	268 730	*279 172*
Oct	234 000	235 813	228 020	224 611	*230 611*
Nov	222 000	221 989	216 282	224 050	*221 080*
Dec	228 000	224 305	222 153	242 223	*229 170*
	3 069 000	3 083 874	3 048 554	3 152 167	3 088 399

From the observation of the curve of Fig. 3, which corresponds to the Thursday 5/10/2017, it turns out that the activities starting at 6 am will also increase the consumption of electricity. Its upward course lasts until 12 noon and stabilizes for the next 3 hours when staff working time is over. This is followed by the downturn in consumption until 7 pm.

Until 10 pm, consumption has a relative stability and reaches its lower limits overnight and up to 6 in the morning.

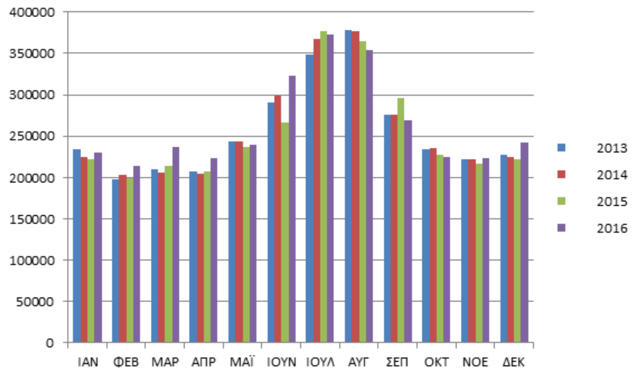

Fig. 2 Load curves of consumed electricity (kWh) of the Hospital for the years 2013-2016

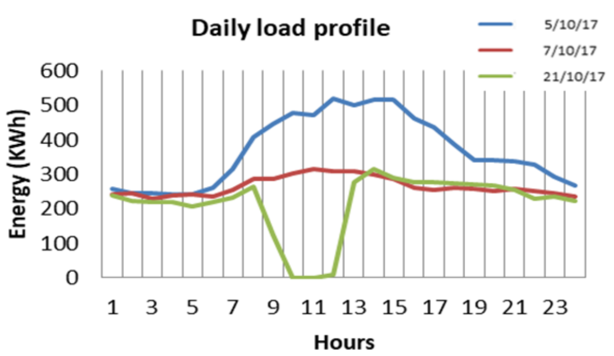

Fig. 3 Graphical depiction of the daily consumption profile of the days Thursday 5/10/2017, Saturday 7/10/2017 and Saturday 21/10/2017

Furthermore, from the comparison of the curves, we see the difference between a week day such as Thursday 5/10/2017 and a weekend day, such as Saturday 7/10/2017, where the hospital does not work in full. For the weekday, the average hourly consumption is about 370 kWh, while the day of the weekend is 265 kWh (about 29% reduction). Comparing the curves on Saturday 7/10/2017 and Saturday 21/10/201, there is a parallel course outside the time period from 8 am to 12 pm, where consumption is zero. This is due to the fact that, at that time, a power outage occurred for the planned maintenance of the medium voltage substation.

Electricity is consumed for the operation of fluorescent lamps with electronic starter, central air conditioners as well as local heat pumps, ventilation and pump systems, six lifts, medical air compression motors, vacuum pumps, various electrical appliances such as refrigerators, televisions, computers and finally fixed and portable medical equipment. The cooling of the hospital is done with three water coolers, four air coolers, and 12 central air-conditioning units. The hospital also has a rooftop air-conditioning unit for the pathologyanatomic department, with a cooling capacity of 21.2 kW and about 330 split-unit air conditioners, with a total cooling capacity of 1230 kW. The total power of the lighting system is 95 kW. The most used luminaires are elongated ceiling lamps with 18W or 36W fluorescent lamps with magnetic ballstring. Lighting control is done manually (common on-off switches).

The hospital is connected to the city's natural gas network and it is the main energy source to meet the hospital's thermal needs. To meet its thermal needs, the Hospital has three natural gas boilers located in an independent boiler room. The two are 3023 kW each, and the third is 1512 kW. Unlike electricity, consumption is increased during the winter period and is noticeably reduced during the summer season, as it can be seen at Table II.

TABLE II
CONSUMPTION (KWH) OF NATURAL GAS FROM THE NATURAL GAS BILLS FOR THE YEARS 2103-2016

Year / Month	2013	2014	2015	2016	*Average*
Jan	555 391	523 194	520 518	446 686	*511 447*
Feb	435 166	442 091	508 561	340 950	*431 692*
Mar	410 956	330 697	461 591	384 788	*397 008*
Apr	173 552	202 155	254 459	187.599	*204 441*
May	129 297	153 978	125 340	135.154	*135 942*
Jun	111 052	123 645	118 099	133 866	*121 666*
Jul	113 147	123 774	123 045	139 607	*124 893*
Aug	110 149	125 462	106 850	126 474	*117 234*
Sep	112 979	136 603	122 699	141 135	*128 354*
Oct	218 191	258 358	212 624	216 176	*226 337*
Nov	313 948	348 664	276 240	349 800	*322 163*
Dec	546 641	619 390	491 218	575 136	*558 096*

It is worth noting that the maximum consumption was in January 2017, when the temperature had fallen to unprecedented low levels (-20 ° C) and for a long time. From the gas consumption bills, the following consumption curves for the years 2013 to 2016 were created.

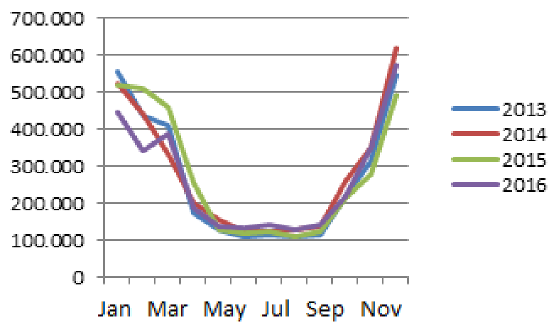

Fig. 4 Graphical depiction of hospital energy consumption (kWh) from gas burning for the years 2013-2016

IV. SOFTWARE DESCRIPTION

The energy calculation and data analysis in the present work will be done using the TEE-KENAK computing tool. This software implements the necessary algorithms for calculating the energy performance of buildings in Greece, based on the European standards methodology. The software takes into account the solar and internal heat gains/loads and thermal losses/loads of the building shell by the method of the semi-steady state of the monthly step [12].

The TEE-KENAK software consists of:

- The insertion mask, which introduces data and parameters related to building shell and electromechanical installations,
- Libraries that include data regardless of the building in question.
- The results mask including the results of the calculations in the form of tables and charts for the existing building, the reference building and the intervention scenarios that the inspector has configured.

After the data are imported, the software automatically creates the reference building. Calculations are then made for both the existing and the reference buildings. Based on the ratio of the primary energy consumption of an existing building (kWh/m^2/year) to the primary energy consumption of the reference building (kWh/m^2/year), the building in question is classified in energy efficiency class (A + to G). In addition, it is possible to configure and evaluate various scenarios of energy saving interventions for the energy upgrading of the building to a better energy class. For each scenario of interventions, the same calculations are made for loads, energy and fuel consumption and annual CO_2 emissions, operating costs, total cost of interventions, energy savings, and a simple payback period. Below are some basic calculations that are performed to import the appropriate data into the software.

The calculation of the average thermal coefficient of the building is given by:

$$U_m = \frac{\sum_{j=1}^{n} A_j\ U_j\ b + \sum_{\iota=1}^{\nu} l_i\ \Psi_i\, b}{\sum_{j=1}^{n} A_j} \text{ [W / (m}^2\text{ K)]} \quad (1)$$

where, Aj is the area of structural element j, U_j is the coefficient of thermal conductivity of the structural element j, Ψi is the coefficient of linear thermal transmittance of the thermal bridge I, l_i is the length of the thermal bridge I and b the reduction factor [13].

The total actual efficiency of boiler n_{gen} is given by [14]:

$$n_{gen} = n_{gm} \cdot n_{g1} \cdot n_{g2} \quad (2)$$

where n_{gm} is the measured efficiency of the boiler given by the manufacturer, n_{g1} is the over-dimensioning factor, and n_{g2} is the insulation coefficient. To calculate n_{g1}, we need to know the ratio P_m / P_{gen} where P_m is the nominal boiler output and P_{gen} is the thermal power of the building. P_{gen} is calculated from the relationship

$$P_{gen} = 2.5 \cdot A \cdot U_m \cdot \Delta T \text{ [W]} \quad (3)$$

where A [m^2] is the total actual external surface of the building shell, U_m [W/(m^2·K)] is the maximum permissible average coefficient of thermal conductivity for the total surface A, ΔT is the temperature difference (23 °C), depending on climatic zone.

For the building to be studied, the values as computed in the spreadsheets are:

$$n_{gm} = 0.931,\ n_{g1} = 0.75,\ n_{g2} = 0.952 \text{ and } n_{gen} = 0.665$$
$$P_{gen} = 1539.1 \text{ kW and } P_m / P_{gen} = 2.64$$

The thermal power P_n, of a hot water heater is usually calculated for an average time of total heat output in 5 hours,

$$P_n = Q_d / 5 \quad (4)$$

The daily thermal load Q_d required (kWh/day) for hot water is given by:

$$Q_d = V_d \cdot c \cdot p \cdot \Delta T / 3600 \quad (5)$$

where V_d [lt/day] is the daily load, p [kg/lt] is the density of water = 1 kg/lt, c [kJ/(kgK)] is the specific heat = 4.18 kJ / (kg·K), and ΔT [K] is the temperature difference between the lowest DHW temperature of the specific area during the year and the DHW temperature (45 ^{o}C). For the building to be studied, the values as calculated in the spreadsheets are:

$$V_d = 30\,400 \text{ Lt / day},\ \Delta T = 38{,}5\ ^oC \text{ and } Q_d = 1358.96 \text{ KJ or } 0.38 \text{ kWh.}$$

V. Software Results

The shape of the building is elongated along the east - west axis and offers a larger surface to the south for collecting solar heat in the winter. Significant free space of the plot is located on the south side, thus ensuring that the building is not shaded by neighboring buildings. On the south side of the building, the majority of treatment rooms are developed, enjoying thermal gains from the sun while being more pleasant and brighter. The rest of the patients' chambers are south-southwest oriented, also participating in the bioclimatic design of the building. On the northern side of the building, it is intended to accommodate areas where their use is short-lived, such as food distribution kitchens, materials warehouses, and doctors' offices.

With the help of the architectural drawings, the opaque and transparent building elements were recorded per thermal zone and orientation. The faces and openings, the total floor area, the total surface area of the heated and cooled spaces, the gross area of the thermal zone, the outer surface of the vertical and horizontal structural elements, and the thickness of the structural elements were recorded. The data of all measurements were recorded in spreadsheets (Microsoft Excel) through which the appropriate calculations were made to obtain those results that will be used for their input to the TEE-KENAK software.

After entering the TEE-KENAK software, the building elements are listed on the home screen / mask named "General Building Data". On the left, the navigation tree of the building in question is "built":

Building: [Building - Zone / Shelf / Systems]
Unheated space: [Shell]

Solar space: [Shell]

In the right section, depending on the selected item from the tree structure, the tab inserts the data. The software has only been created in the Greek version, so there is no point in presenting the screens of the program.

On the first screen, the basic information of the building, such as its use, the name of the owner, the ownership (public), the postal address, the contact details of the person responsible, the climate zone (C) and the data sources (architectural data, energy consumption invoices, maintenance sheets) are presented. The total surface area and volume of the building, its useful area and volume, the chilled surface and volume, the number of floors, the ground floor and a typical floor's height, the exposure of the building and finally the number of thermal zones, non - heated areas and solar areas are filled in the 'general' tab of the building.

TABLE III
'GENERAL' TAB OF THE SOFTWARE TEE - KENAK

Building use :	Hospital
Total area (m^2) :	16 403
Useful area (m^2) :	15 000
Chilled area (m^2) :	15 000
Total volume (m^3) :	59 050.8
Useful volume (m^3) :	54 000
Chilled Volume (m^3) :	54 000
Number of floors :	10
Height of a typical floor :	3.6
Height of the ground floor :	3.6
Building's exposure :	Protected
Number of thermal zones :	5
Number of non – heated areas :	1
Number of solar areas :	0

TABLE IV
'WATER SUPPLY AND DRAINAGE' TAB OF THE SOFTWARE TEE – KENAK

Network type	Number	Power (kW)	Hours of operation
Water supply	2	20	450
Drainage	3	14	220
Water supply	2	10	400

TABLE V
'MECHANICAL LIFT' TAB OF THE SOFTWARE TEE – KENAK

Network type	Number	Power (kW)	Hours of operation
Mechanical lift	10	98	4000

Tables IV and V refer to the water supply and drainage of the building and to its mechanical lift.

The main building was divided into four zones, while the Symeonideion building was classified as a fifth separate zone because it has an independent cooling-heating-ventilation system from the rest of the building.

Zone 1: Patient rooms
Zone 2: Surgery premises
Zone 3: Outpatient and office premises
Zone 4: Waiting rooms
Zone 5: The first wing (Symeonideion building)

TABLE VI
GENERAL INFORMATION FOR EACH ZONE

Thermal zone	Use	Total area (m^2)	Air penetration through openings (m^3/h)	Number of roof fans
1	Hospital (patient rooms)	2989.2	2444	1
2	Hospital (surgery space)	264.81	488	0
3	Hospital (outpatient offices)	5339.4	5166	3
4	Waiting rooms	3554	709	10
5	Hospital (outpatient offices)	2745.3	1386	5

In the software screen for each thermal zone, as it can be seen on Table VI, we report the use of space, the total area of the zone, the average domestic hot water (DHW) consumption, the DHW automatic control devices, the reduced thermal capacity, the category of control devices for heating and cooling, the air penetration through openings, the number of chimneys, the number of ventilation slots, the number of doorways and finally the number of roof fans.

It is worth noting that the average consumption of hot water in the zone 1 is 11 096 m^3/year while in the other zones there is no requirement for DHW. Also, the number of doorways in zone 4 is three and in zone 5 only one, while in the remaining zones is zero. There are no automatic control devices for DHW in any of the five zones. In all zones, the reduced thermal capacity is 280 kJ/m^2K, and the category of control devices for heating and cooling is D. Finally, the number of chimneys and the number of ventilation slots is everywhere zero.

The data entered in the building shell opaque surfaces tab are presented on Table VII.

TABLE VII
THERMAL COEFFICIENT OF STRUCTURAL DATA AND OPENINGS

S/N	Opaque surface type	Description	γ	β	Width W (m)	Height H (m)	Surface area (m^2)	Bearing structure area 15% (m^2)	Openings area (m^2)	Wall area (m^2)
1	Exterior wall	W1	230	90	2.8	3.36	9.41	1.41	4.54	3.46
2	Exterior wall	W2	230	90	3	3.36	10.08	1.51	4.54	4.03
3	Exterior wall	W3	230	90	3	3.36	10.08	1.51	4.54	4.03
4	Exterior wall	W4	230	90	3	3.36	10.08	1.51	4.54	4.03
5	Exterior wall	W5	230	90	1.5	3.36	5.04	0.76	2.48	1.80
6	Exterior wall	W6	230	90	5.2	3.36	17.47	2.62	8.26	6.59
7	Exterior wall	W7	230	90	1	3.36	3.36	0.50	0	2.86
8	Exterior wall	W8	140	90	0.525	3.36	1.76	0.26	0.87	0.63
9	Exterior wall	W9	140	90	5.25	3.36	17.64	2.65	8.66	6.33
10	Exterior wall	W10	140	90	4.2	3.36	14.11	2.12	6.93	5.07

Table VIII gives us the thermal coefficient of the structural data and openings of the building. The shell screen displays the data collected from building control for opaque surfaces, ground contact surfaces and transparent surfaces. The following tables illustrate the details of only a part of the opaque and transparent surfaces of the building shell. In fact, the tables refer to the surfaces of the A wing. Due to the large number of structural elements and openings of the building, it is impossible to list all the tables.

TABLE VIII
THERMAL COEFFICIENT OF STRUCTURAL DATA AND OPENINGS

	Bearing structure	Wall	Opening
U (W/(m^2 K))	3.4	3.05	2.9

According to the Technical Directive 20701-1 of the Technical Chamber of Greece, the area occupied by the building's body as a percentage on the surface of its facade in corner buildings before 1981 with a floor number of less than five is 15%. The final column is calculated by subtracting the area of the openings and the bearing structure area from the total surface of the wall. The variable γ gives us the orientation of the specific surface while the variable β gives us the slope of the structural element. The orientation variable gets the value 0 for North, 90 for East, 180 for South and 270 for West. The slope variable gets the value of 90 for vertical elements, 0 for ceilings and 180 for floors. The other elements filled in the tab of the opaque components are absorption (α) and emittance (ε) coefficients, which are equal to 0.8 for vertical structural elements with conventional material and white coat. It is also necessary to fill the shading coefficients for each surface and for each opening (balcony door or window).

Shading factors refer to shading from obstacles in the near-horizon, shading from canopies and awnings and also shading from lateral projections to the left and right. These factors depend on the height and width of the element, its distance from the obstacles and its orientation. They get the value 1 when the surfaces are shadowless while they get the value 0 when they are completely shaded. The hospital under study is in an ideal position and it is not shaded by opposing obstacles, shoulders and side projections, so all shading factors are considered equal to one.

Table IX gives us the type of openings (ground window), the orientation and slope of each element, the width, the height and the area of each opening, the frame material (wood, aluminum, synthetic) and the type of glass (single, double with 6 or 12mm air gap). It also gives us the air penetration coefficient and the total penetration resulting by multiplying the area of the opening by the penetration coefficient. Finally, the length and width and the area of the lighting zones used to calculate the percentage of the illumination area for the lighting tab are completed in the software. The rest of the elements filled in the transparent surface tab are the coefficient of thermal conductivity U given in Table VIII, the reflectance coefficient g_w depending on the type of opening which takes values from a table of the aforementioned technical directive, and finally the shading factors as analyzed above.

There are no passive solar systems in the building, so the corresponding tab of the software is not completed. Heat data include data such as the type of heating output (boiler, heat pump, fireplace), energy source (oil, natural gas, electricity, biomass), heating period (in months), power (kW), boiler efficiency (%), type of networks (central or local), insulation of distribution pipelines, type and degree of performance of terminal units and finally the type (pump) and power (kW) of auxiliary systems.

It is worth noting that the heating period is from October to April, so the respective cells of these months are filled by 1, while the rest months are filled by zero. The results are presented on Table X.

TABLE IX
OPENINGS DATA OF THE HOSPITAL BUILDING

S/N	Opening type	γ	β	Width W (m)	Height H (m)	Openings area (m^2)	Material	Glass pane	Ventilation coefficient ($m^3/h/m^2$)	Air penetration (m^3/h)	Lzφφ (m)	Wzφφ (m)	ZΦΦ (m^2)
1	Ground window	230	90	2.75	1.65	4.5	Aluminum	double	6.8	30.86	4.13	4.81	19.85
2	Ground window	230	90	2.75	1.65	4.5	Aluminum	double	6.8	30.86	4.13	4.81	19.85
3	Ground window	230	90	2.75	1.65	4.5	Aluminum	double	6.8	30.86	4.13	4.81	19.85
4	Ground window	230	90	2.75	1.65	4.5	Aluminum	double	6.8	30.86	4.13	4.81	19.85
5	Ground window	230	90	1.5	1.65	2.4	Aluminum	double	6.8	16.83	4.13	3.56	14.70
6	Ground window	230	90	2.5	1.65	4.1	Aluminum	double	6,.8	28.05	4.13	4.56	18.82
7	Ground window	230	90	2.5	1.65	4.1	Aluminum	double	6.8	28.05	4.13	4.56	18.82
8	Ground window	140	90	0.53	1.65	0.8	Aluminum	double	6.8	5.89	4.13	2.59	10.67
9	Ground window	140	90	5.25	1.65	8.6	Aluminum	double	6.8	58.91	4.13	7.31	30.16
10	Ground window	140	90	4.2	1.65	6.9	Aluminum	double	6.8	47.12	4.13	6.26	25.83

In the cooling tab, the data are recorded in a similar manner to the heating, in four sub-menus:

1. Production
2. Distribution network
3. Terminal units
4. Auxiliary units

In particular, data filled are the type of heat generation system (heat pumps), the energy source (electricity), the efficiency (EER), the heating period (in months), the type of network (central or local), the percentage of losses in the distribution network, the type and the degree of performance of the terminal units, and finally the type, the number and the total power of auxiliary systems for cooling. It is worth noting that the cooling period is from June to September, so the respective cells of these months are filled by 1, while the rest months are filled by zero.

TABLE X
HEATING SYSTEM OF THE HOSPITAL

Heat type	Energy source	Power (kW)	Efficiency
Boiler	Natural gas	1539.15	0.931
Type of distribution network	Power (kW)	Transit area	Efficiency
Hot distribution network	386.82	internal piping	0.93
Terminal units		Efficiency	
Classic Heaters with slices		0.86	
Auxiliary systems		Power (kW)	
3 Pumps		4.71	

TABLE XI
COOLING SYSTEM OF THE HOSPITAL

Cooler type	Energy source	Power (kW)	EER
Air cooler	Electricity	129	2.54
Air heat pump	Electricity	358	2.86
Type of distribution network	Power (kW)	Transit area	Efficiency
Cool distribution network	15	internal piping	1
Terminal units		Efficiency	
Split units		0.93	
Auxiliary systems		Power (kW)	
12 Pumps		2.80	

Similarly, the data entered in the DHW tab are in four sub-sections, production, distribution network, storage system if available and auxiliary units. The natural gas boiler is used throughout the whole year for hot water.

There are no solar collectors, mechanical ventilation or a damping system in the hospital, so the corresponding tabs remain empty. In the fields of the tab concerning the building's lighting, elements such as installed lighting power, natural light area, lighting control automation systems, motion detection automation systems, and artificial lighting zones according to the areas slammed into the building under study, are listed.

After the data for the inspected building are entered, the software automatically creates the reference building. Then, calculations are done (through the Execution command) for both the existing and the reference building about the monthly loads and the corresponding energy consumption (for heating, cooling, hot water and lighting), fuel consumption, primary energy and CO_2 emissions. The results of the calculations are presented on Table XIV. Furthermore, the simulation revealed (Table XV) that natural gas consumption for the building in question is very close to actual consumption, which indicates that the simulation results are very close to the real energy data of the building.

Table XVI presents the fuel consumption for both electricity and natural gas, and also the CO_2 emissions from each energy source.

The building's simulation shows a primary energy consumption of 396.4 kWh/m^2 and compared to the reference building that consumes 203.64 kWh/m^2, the building is considered to be energy-inefficient. To classify the building into an energy class, we control the ratio of the total primary energy of the building under consideration to the overall primary energy of the reference building. The result of the division (396.4/203.6) is 1.95, a value that is between the values of 1.82 and 2.27 which are the limits of category E.

TABLE XII
DHW TAB OF THE SOFTWARE TEE – KENAK

DHW type	Energy source	Power (kW)	Efficiency
Boiler	Natural gas	1539.15	0.944
Type of distribution network	Recirculation	Transit area	Efficiency
DHW distribution network	yes	internal piping	0.67
Storage system		Efficiency	
Not exist		1	
Auxiliary systems		Power (kW)	
3 Pumps		1.40	

TABLE XIII
LIGHTING TAB OF THE SOFTWARE TEE - KENAK

Installed power (kW)	*28.77*
Natural light area (%)	*0.35*
Artificial lighting zones at 100lux (%)	*100*
Natural lighting control automation	*Manual*
Motion detection automation	*Manual switch touch-quench*
Security light	*Yes*
Back-up system	*Yes*

TABLE XIV
ANNUAL ENERGY DEMAND RESULTS FOR THE HOSPITAL BUILDING

Energy requirements (kWh/m^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Yearly*
Heating	13.9	10.1	6.4	1.7	0	0	0	0	0	0.5	5.5	11.8	*49.8*
Cooling	0	0	0	0	0	20.6	27.7	25.9	0	0	0	0	*74.3*
DHW	2.8	2.5	2.6	2.3	2	1.6	1.5	1.5	1.6	2	2.3	2.7	*25.5*

TABLE XV
ANNUAL FINAL ENERGY CONSUMPTION RESULTS FOR THE HOSPITAL BUILDING

Energy consumption (kWh/m^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Yearly*
Heating	47.5	35.5	24.3	8.4	0	0	0	0	0	2.8	21	41	*180.5*
Cooling	0	0	0	0	0.6	9.9	13.6	12.6	0.5	0	0	0	*37.2*
DHW	3.7	3.2	3.4	2.9	2.6	2.1	2	1.9	2.1	2.6	3	3.5	*32.9*
Lighting	1.5	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	*18.2*
Total	52.7	40.1	29.2	12.9	4.7	13.5	17.1	16.1	4.1	6.9	25.5	46	*268.8*

TABLE XVI
FIGURES OF THE BUILDING RESULTS OF SPECIAL ENERGY

Energy source	Fuel consumption (kWh/m^2)	CO_2 emissions (kg/m^2)
Electricity	68.5	67.7
Natural gas	207.2	40.6
Total	268.8	108.4

TABLE XVII
PRIMARY ENERGY END-USE RESULTS FOR THE BUILDING IN QUESTION AND THE REFERENCE BUILDING

Primary energy per end use (kWh/m^2)	Reference building	Existing building
Heating	30.3	201.3
Cooling	58.6	107.7
DHW	29.9	34.6
Lighting	84.7	52.8
Total	203.6	396.4
Classification	-	E

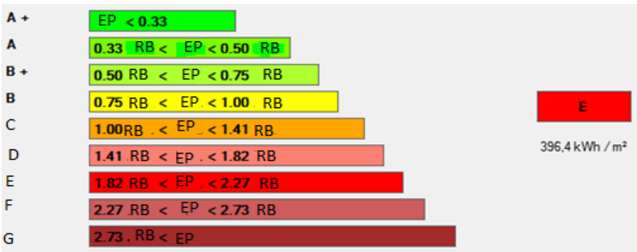

Fig. 5 Results of the energy performance of the building

VI. ENERGY SCENARIOS APPLIED

The energy consumption of the building is important. Much of the consumption is intended to cover the thermal and cooling loads of the building. There is considerable scope for improving the thermal and cooling needs of the building in this sector. Therefore, for the energy upgrading of the building, the following interventions are considered as high priority:

- Thermal insulation to the horizontal masonry of the building
- Thermal insulation to the roof of the building
- Replacement of window frames
- Replacement of single glass window frames
- Installation of shades on the south side of the 3rd Wing
- Installation of ceiling fans
- Insulation of distribution networks
- Installation of thermostatic switches in radiators
- Replacement of cooling tower
- Replacement of lighting corridors with LED lights
- Lighting devices to the WC via person presence sensors
- Upgrading the BEMS system by adding a) control light and b) electrical consumables per floor by installing digital meters in each electrical floor subpanel [15].

The software enables the user to formulate and evaluate up to three proposals to improve the energy performance of the building. The three scenarios are presented below:

Scenario 1: Upgrading Building Enclosure (Thermal Insulation-Doors-Shades). Upgrading from E to C category

Scenario 2: Upgrading of Electromechanical installations (Ceiling fans-Thermostatic heads-Lighting-BEMS-Cooling Towers-Insulation of networks). Upgrading from E to D category

Scenario 3: Upgrading Building Enclosure + Upgrading of Electromechanical Installations. Upgrading from E to B category. This scenario is therefore selected for the presentation of the results thereafter.

More specifically, based on the ratio of the primary energy consumption (kWh / m^2 / year) of the building to the primary energy consumption of the reference building (kWh / m^2 / year), the three scenarios show:

Scenario 1: 227.5 / 203.6 = 1.12 1.00 < 1.12 < 1.41 (Energy class C)

Scenario 2: 296.9 / 203.6 = 1.46 1.41 < 1.46 < 1.82 (Energy class D)

Scenario 3: 181.2 / 203.6 = 0.89 0.75 < 0.89 < 1.00 (Energy class B)

The results are presented on Table XVIII, while Table XIX shows the benefits from the implementation of all proposed interventions.

According to Table XX and taking into account the total annual primary energy savings from the total interventions and the total cost of the interventions, the total annual primary energy savings are 215.2 kWh / m^2 or 54.3%.

The costs of the installations implemented for the two first scenarios are described on Table XXI. Scenario 3 combines the first two, so its cost is the total cost of scenarios 1 and 2.

TABLE XVIII
PRIMARY ENERGY END-USE RESULTS FOR THE BUILDING THAT EMERGED APPLYING THE COMBINATION SCENARIO AND THE REFERENCE BUILDING

Primary energy per end use (kWh/m^2)	Reference building	Existing building	Scenario 1	Scenario 2	Scenario 3
Heating	30.3	201.3	84.1	142.9	63
Cooling	58.6	107.7	56.1	76.1	40.2
DHW	29.9	34.6	34.6	34.6	34.6
Lighting	84.7	52.8	52.8	43.4	43.4
Total	203.6	396.4	227.5	296.9	181.2
Classification	-	*E*	*C*	*D*	*B*

TABLE XIX
ENERGY AND CO2 SAVINGS

Fuel consumption	Consumption (%)	Primary Energy (%)	CO_2 Emissions (%)
Electricity	*45.9%*	*47.9%*	*45.9%*
Natural Gas	*63%*	*58.6%*	*63%*
Total	58.5%	54.3%	52.3%

VII. CONCLUSION

The present work reflects the existing energy situation of the hospital buildings and examines the possibility of upgrading it. The buildings of the Hospital due to their age show great losses. After thoroughly recording and studying the characteristics of the buildings, it is noted that there are many possibilities of interventions in both the shell and the electromechanical installations to improve the energy status of the buildings by upgrading them from the current energy category E to the B category. Finally, it appears that with a simple repayment period, the investment is amortized at 4.1 years for Scenario 3.

TABLE XX
SAVINGS AND REPAYMENT PERIOD FOR ALL THE INTERVENTIONS

Costs and Savings	Reference building	Existing building	Scenario 1	Scenario 2	Scenario 3
Operating cost (€)	151186.5	339330.8	182822.1	252381.6	145194.3
Initial investment cost (€)			704.426.4	85.275	789.701.4
Primary energy saving (kWh/m^2)			168.9	99.4	215.2
Primary energy saving (%)			42.6	25.1	25.4
Energy saving value (€/kWh)			0.3	0.1	0.2
Reduction of CO_2 emissions			42.9	27.2	56.7
Repayment period (years)			4.5	1	4.1

TABLE XXI
COST OF TOTAL INTERVENTIONS

1. Building Shell Upgrading	Quantity	Cost
Replace double-glazed window frames	141.28 m^2	39 558.4 €
Replacement of single window frames	54.34 m^2	15 216 €
Replacement of glass blocks	372.74 m^2	223 644 €
Thermal insulation (side + roof)	8405.69 m^2	411 879.2 €
Horizontal Exterior Blinds	141.28 m^2	14 128.8 €
Subtotal scenario 1	704 426.40 €	
2. Electromechanical installations upgrading	***Quantity***	***Cost***
Ceiling fans	150 pieces	22.500 €
Replacement of cooling towers	2 pieces	30.000 €
Distribution piping insulation	Flat rate	10.000 €
Thermostatic radiator heads	400 pieces	4.000 €
Lighting interventions	185 pieces	13.875 €
Upgrading BEMS-presence sensors, digital multimeters, display panel	Flat rate	4.900 €
Subtotal scenario 2	85.275 €	
Total	789 701.40 €	

REFERENCES

[1] Agelidis G., Gaglia A., Giannakidis G., Daskalaki E., Dimoudis A., Dilivas E., Doukas C., Kteniadakis M., Balaras K. (2011), Introduction to the energy sector, Training of Energy Inspectors Educational Material, Technical Chamber of Greece, Athens.
[2] Rokkou K., "Energy Saving-Lesson Notes in the Postgraduate Curriculum entitled" Energy Technologies and Automation Systems ", Larissa 2016.
[3] Baksevanou A, Course Notes "Energy Management of Buildings", MSc "Energy Technologies and Automation Systems", Chapter 1, April 2017.
[4] Kasapidou M. Diploma thesis "Energy Management in Hospital Facilities -Implementation in the Hippocratic Hospital of Athens" pp: 23-24.
[5] Ministry of Development, Center for Renewable Sources and Energy Saving, http://www.cres.gr/energy-saving/enimerosi_bioclimatikos.htm, (Accessed on 09.11.2017).
[6] WildWaterWall, https://sites.google.com/site/wildwaterwall/eliaka-spitia/bioklimatikos schediasmos-t-o-t-e-e (Accessed on 20/11/2017).
[7] Building Energy Performance Regulation, Ministerial Decision. No D6 / B / Dom.5825 / 30-03-2010.
[8] Green Hospital- project, (2015), http://www.greenhospital-project.eu/ (Accessed on 19.12.2017).
[9] TOTE 20701-3 / 2010 "Climate Data of Greek Regions".
[10] Theageneio Hospital, http://www.theagenio.gov.gr/ (Accessed on 12.11.2017).
[11] TEE-KENAK Software, http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/tee_kenak (Accessed on 03/02/2017).
[12] TOTE 20701-3 / 2010 " Analytical national parameter specifications for the calculation of the energy performance of buildings and the issue of the energy performance certificate.
[13] Androutsopoulos A., Aravantinos D., Axrilis K., Theodossiou Th., Tsikaloudaki K. (2011), Climate and internal environment. Bioclimatic Design of Buildings, Training of Energy Inspectors Educational Material, Technical Chamber of Greece, Athens.
[14] TOTE 20701-2 / 2010 "Thermophysical properties of building materials and control of the thermal insulation of buildings".
[15] Ministry of Development, Center for Renewable Sources and Energy Saving, http://www.cres.gr/energy_saving/Ktiria/energeiaki_diaxeirisi_metra_exikonom.htm, , (Accessed on 10.11.2017).