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ASSESSMENT OF ALTERNATIVE TYPOLOGIES OF TERTIARY SECTOR BUILDINGS TOWARDS ZERO ENERGY

MASTER THESIS

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ABSTRACT

According to European Union's (EU) latest release, countries within Europe are only 2% and 4% regarding the final and primary energy consumption targets respectively, far from the 20% energy efficiency targets posed by the 2012/27/EU Directive.

Regarding buildings sector, the stipulations of the recent revision of the Energy Performance of Buildings Directive (2018/844/EU), aim to enhance the efforts for decarbonization of the national building stocks of the State Members by 2050.

In Greece, tertiary sector buildings are responsible for the 12% of the final energy consumption, with the majority of them have been constructed before 1980, consuming a large amount of energy and presenting a low performance in terms of energy efficiency, providing, therefore, a great potential for energy saving interventions.

This Master Thesis studies the potential energy saving of 4 different types of tertiary sector buildings in order to benchmark energy savings, financial and environmental efficient results. Benchmarking included the study of a 15 buildings complex Resort and Spa Hotel in Lasithi, a bioclimatic architecture Office building in Athens, a Leisure and Sports centre in Chania and a Pediatric and Maternity Clinic in Athens. The methodology approach based on the standardization tool developed within the framework of TRUST EPC South initiative, funded by the EU.

Several energy saving interventions were investigated for each case, according to energy audits findings, simulation results and owners' preferences. Results showed a potential consumed energy saving from 62,7% to 8,3% of total consumption for a payback period from 3,1 to 6,6 years. The investment cost per kWh saved for all included cases from 0,01€/kWh to 0,13 €/kWh, highlighting the most efficient measures in terms of energy and financing. The corresponding investment cost per kg of CO_2eq saved was varied from 0,007€/kgCO_2eq to 0,14€/kgCO_2eq for the examined measures of all cases, identifying the measure achieving the higher decarbonization purchasing the less amount of money.

Keywords: tertiary sector buildings, benchmarking, energy savings, buildings typologies

Extended Summary in Greek

Σύμφωνα με την πρόσφατη ανακοίνωση της Ευρωπαϊκής Ένωσης (ΕΕ), οι ευρωπαϊκές χώρες απέχουν μόλις 2% και 4% από τους στόχους που έχουν θεσπιστεί για την ενεργειακή απόδοση μέσω της Οδηγίας 2012/27/ΕΕ, σχετικά με την κατανάλωση τελικής και πρωτογενούς ενέργειας, αντίστοιχα.

Οι διατάξεις της πρόσφατης αναθεώρησης της Οδηγίας για την ενεργειακή απόδοση των κτιρίων (2018/844/ΕΕ), στοχεύουν στην ενίσχυση των προσπαθείων για μείωση των εκπομπών του διοξειδίου του άνθρακα από το εθνικό κτιριακό απόθεμα των κρατών μελών της ΕΕ ως το 2050.

Στην Ελλάδα, τα κτίρια του τριτογενή τομέα ευθύνονται για την κατανάλωση του 12% της τελικής καταναλισκόμενης ενέργειας, με την πλειοψηφία αυτών να έχουν κατασκευαστεί πριν το 1980, έχοντας υψηλές ενεργειακές απαιτήσεις και χαμηλή ενεργειακή απόδοση, παρέχοντας ως εκ τούτου τη δυνατότητα για αποτελεσματικές παρεμβάσεις εξοικονόμησης ενέργειας.

Σύμφωνα με την έρευνα για την κατανάλωση ενέργειας στον τριτογενή κτιριακό τομέα, τα κτίρια γραφείων, τα εμπορικά κτίρια και τα ξενοδοχεία αποτελούν τους τύπους κτιρίων με τις μεγαλύτερες καταναλώσεις στις χώρες της Ευρώπης. Στην Ελλάδα συγκεκριμένα, τα κτίρια γραφείων καταναλώνουν περίπου το 46% της συνολικής ενέργειας που απαιτούν τα κτίρια του τριτογενή τομέα, με τα ξενοδοχεία να ακολουθούν στη συνέχεια.

Η παρούσα διατριβή εξετάζει την εξοικονόμηση ενέργειας σε τέσσερις διαφορετικούς τύπους κτιρίων του τριτογενή τομέα με στόχο τη συγκριτική αξιολόγηση σε επίπεδο εξοικονόμησης ενέργειας αλλά και οικονομικών και περιβαλλοντικών δεικτών. Η μελέτη εξετάζει την περίπτωση μιας ξενοδοχειακής μονάδας 15 κτιρίων στο Λασίθι, ενός κτιρίου γραφείων βιοκλιματικής αρχιτεκτονικής στην Αθήνα, ενός Ψυχαγωγικού και Αθλητικού κέντρου στα Χανιά και μίας Μαιευτικής – Γυναικολογικής και Παιδιατρικής Κλινικής στην Αθήνα. Η μεθοδολογία βασίζεται στο εργαλείο τυποποίησης GREPCon που αναπτύχθηκε στο πλαίσιο της Ευρωπαϊκής Πρωτοβουλίας TRUST EPC South, η οποία χρηματοδοτείται απο την Ευρωπαϊκή Επιτροπή στο πλαίσιο του προγράμματος Ορίζοντας 2020.

Ένα μεγάλο εύρος μέτρων εξοικονόμησης ενέργειας μελετήθηκαν σύμφωνα με τα αποτελέσματα των ενεργειακών επιθεωρήσεων, των αποτελεσμάτων προσομοιώσεων και τις προτιμήσεις και προτεραιότητες των ιδιοκτητών. 47 διαθέσιμα μέτρα εξοικονόμησης περιλαμβάνονται στο εργαλείο τυποποίησης GREPCon, τα οποία διακρίνονται σε 5 κατηγορίες:

Φωτισμός, Συστήματα Ψύξης/Θέρμανσης/Αερισμού, Ζεστό Νερό Χρήσης, Ανανεώσιμες Πηγές Ενέργειας και γενική κατηγορία μέτρων.

Τα αποτελέσματα έδειξαν επίτευξη εξοικονόμησης ενέργειας από 62,7% εώς 8,3% ανάλογα τον τύπο του κτιρίου, με αντίστοιχη περίοδο αποπληρωμής από 3,1 εώς 6,6 χρόνια. Το κόστος επένδυσης ανά μονάδα ενέργειας που εξοικονομείται κυμαίνεται μεταξύ 0,01€/kWh και 0,13 €/kWh για τα μέτρα που εξετάζονται σε κάθε περίπτωση, αναδεικνύοντας τα πιο αποδοτικά μέτρα ως προς την ενέργεια και το κόστος. Το αντίτοιχο κόστος επένδυσης ανά κιλό CO_2eq που εξοικονομείται, κυμαίνεται μεταξύ 0,007€/kgCO_2eq και 0,14€/kgCO_2eq, για τα εξεταζόμενα μέτρα όλων των περιπτώσεων, προσδιορίζοντας με αυτό το τρόπο τα μέτρα που επιτυγχάνουν τη μεγαλύτερη εξοικονόμηση διοξειδίου του άνθρακα με το μικρότερο επενδυτικό κόστος.

Λέξεις κλειδιά: κτίρια τριτογενή τομέα, ενεργειακή αξιολόγηση, εξοικονόμηση ενέργειας, συγκριτική ανάλυση

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Abbreviation List

AHU	Air Handling Units
BMS	Building Energy Management System
DH	District Heating
DHW	Domestic Hot Water
EPBD	Energy Performance of Building Directive
EPC	Energy Performance Contracting
ESCO	Energy Saving Company
EU	European Union
GHG	Green House Gas
HVAC	Heating, Ventilation and Air – Conditioning
NEEAP	National Energy Efficiency Action Plan
NZEB	Near Zero Energy Building
VRV	Variable Refrigerant Volume

Introduction

On 8th October 2018, the Intergovernmental Panel on Climate Change (IPCC) was officially presented the Special Report on Global Warming of 1,5°C regarding the benefits of limiting global warming to 1,5°C compare to 2°C, and the far-reaching consequences of global warming increasing by only 0,5°C. Benefits to ecosystems and people societies in terms of environmental, financial and well-being schemes arise from the Special Report. [1]

Adopting the Paris Agreement at the COP21 in Paris in November of 2016, all countries had a common agreement on working to limit global temperature rise below 2°C in long-term, contributing therefore to Green House Gas emissions reduction and corresponding CO_2 emissions globally. [2]

A low-carbon economy consists the flagship policy of European Commission, delivered by its roadmap with suggestions to greenhouse gas emissions reduction by 80% by 2050, compared to 1990 levels, feasible and affordable low-carbon transition and contribution of all sectors associated: transport, power, residential and tertiary, industry, agriculture and other. [3]

Decarbonization of the buildings sector by reducing the emissions from residential and tertiary sector buildings by 90% until 2050, is the main EU target on the roadmap towards 2050. Energy performance aimed to drastically and rapidly improve through renovations in EU old buildings were currently representing an important share, integration of passive house technologies in the new constructed buildings among the Member States and increasing the penetration of renewables in electricity grids. Fossil fuels will gradually be replaced by renewables and their increasing share in electricity production, reaching the 2050 goals of EU. [3,4] Currently, the penetration of renewables in energy mix of EU has significantly increased from 5,1% in 1996, in 13,2% in 2016, according to new European Commission's Energy in Figures Report for 2018. [5]

The old and low-rate innovated buildings of the tertiary sector in Europe presented a great potential for energy saving interventions in order to achieve the decarbonization goals for the sector, which is the highest consumer of energy within the Member States.

Within this framework and taking under consideration the current facts of the sector, a new standardized tool was developed in order to provide benchmarking of different types of tertiary sector buildings. The energy performance of each building along with the potential energy saving by implementing a number of standardization measures, and their corresponding financial and environmental performance were investigated by the present Thesis.

The evaluation of a variety of measures regarding the building envelope, the heating, air conditioning and ventilation systems (HVAC), the smart systems integrated in the building and plenty of others, is presenting within this study for a variety of types of buildings, as pointed out from market analysis, in order to enhance to the decarbonization of the sector.

Chapter 1
The buildings of tertiary sector in European and national level

Building sector in EU

Buildings are responsible for the 40% of total final energy consumption within EU Members, reaching the CO_2 emissions associated at 36% of total EU emissions. It' s worth mentioning that the 35% of existing buildings in EU are over 50 years old, and 75% of the total building stock is energy inefficient. Generally, the building sector in EU consists the largest single consumer of energy, providing though, a great potential towards a more efficient path. [6]

Average consumed energy of buildings within European Union State Members varies from 70 kWh/m^2 to 230 kWh/m^2, depending on the building type.

The EU average for energy consumption for all types of buildings stated around 210 kWh/m^2 at 2015, while non-residential buildings required about 55% more energy for their needs compare to residential, 286 kWh/m^2 in contrary to 185 kWh/m^2. [7]

Within the EU Member States, the distribution of floor area per sector is not homogenous. On average, regarding the service sector, over the 30% of floor area corresponds to offices, 27% to wholesale and 16% to education. [8]

Their higher amount of energy associated both to their size and occupancy, but also to the type of services offered. For instance, compared to other commercial buildings, lodging facilities have special operational schedules, especially those with the annual operation, occupancy patterns and occupants needs. Offering multiple types of services such as restaurants, leisure facilities, pools, spa, bars etc, targeting to offer quality services to the occupants, hotels are included among the buildings with significant energy consumption and therefore cases with great potential energy saving.

Hospitals, due to the 24h operation have intensive requirements in heating, air conditioning, lighting, electricity consumption, along with its big surface, increased needs for hot water and thermal comfort, sterilization needs and needs of medical equipment and machines, consist an extremely challenging case for energy saving potential. [9]

In general, energy consumption in the tertiary sector was increased rapidly from 2000 to 2008 by 2,55% per year, presenting a decreasing rate onwards 2008 due to the economic downturn. A number of policies and measures are presented from EU in order to horizontally implemented through national legislation of Member States. Areas which need to be under consideration for the next years are building renovation strategies for the total of Member countries, along with overcoming of financial barriers and increasing trust among stakeholders. [10]

Legislation for Energy Efficiency

According to European Union's (EU) release for 2017 energy consumption, European countries are only 2% and 4% far from the 20% energy efficiency targets posed by the 2012/27/EU Directive, with regard to the final and primary energy consumption target respectively. (1) [11]

Despite this fact, almost 75% of the buildings in EU are energy inefficient, while 35% were built before 1960. [12] The share of the tertiary sector in the EU's final energy consumption reached to 13,55% for 2015, whereas a rise by 21,5% is recorded for the last 15 years, for 2000 to 2015. In general, the tertiary sector has a great potential for energy saving, but energy saving interventions and policies are not quite often a priority for business and organizations. Lack of incentives for investments has an important role for owners to make a decision for energy efficiency renovations. Energy Performance Contracts consists a method for projects implementation through a long-term contractual agreement, with no need of initial capital by the tertiary sector business. [13]

The EU is making efforts to improve the energy efficiency of the building sector by applying policies to support and promote renovations of old structures, implementing also new standards for the new buildings. According to the last release, the current renovations rate is between 0.4 and 1.2% per year. In order to achieve the EU the long-term goal for reduction of GHG emissions by 80-95% by 2050, compared to 1990 levels, that low percentage should be increased. [14]

The latest version of the Energy Performance of Buildings Directive (2018/844/EU) came into force recently, highlighting the aim of national building stocks decarbonisation by 2050 for all the Member States. Encouraging automated and control systems by introducing smart technologies for new structure, is also in the first line of EU guidelines for energy-efficient commercial buildings and residences, combining with other sectors decardonisation such as transportations and electromobility. [15]

The market of the tertiary sector in EU

The development of flexible market policies and mechanisms can evidentially help to overcome barriers, especially the financial ones, among the EU Member States, in order to achieve EU targets more efficiently and smoothly. The most representative mechanism within the market is the Energy Performance Contracts (EPC). [16]

Analysing the national demands of 6 European countries (Portugal, Spain, Italy, France, Croatia and Greece) through the interviews of more than 180 stakeholders, resulting the great potential of development of tertiary sector buildings within this market.

The demand analysis study included a review of available National Energy Efficiency Plans for each country, highlighted the segments of the sector have been pointed out as the main target:

offices, commercial buildings and hospitality (Figure 2), along with the share of used energy forms in the sector's buildings (Figure 1). [16]

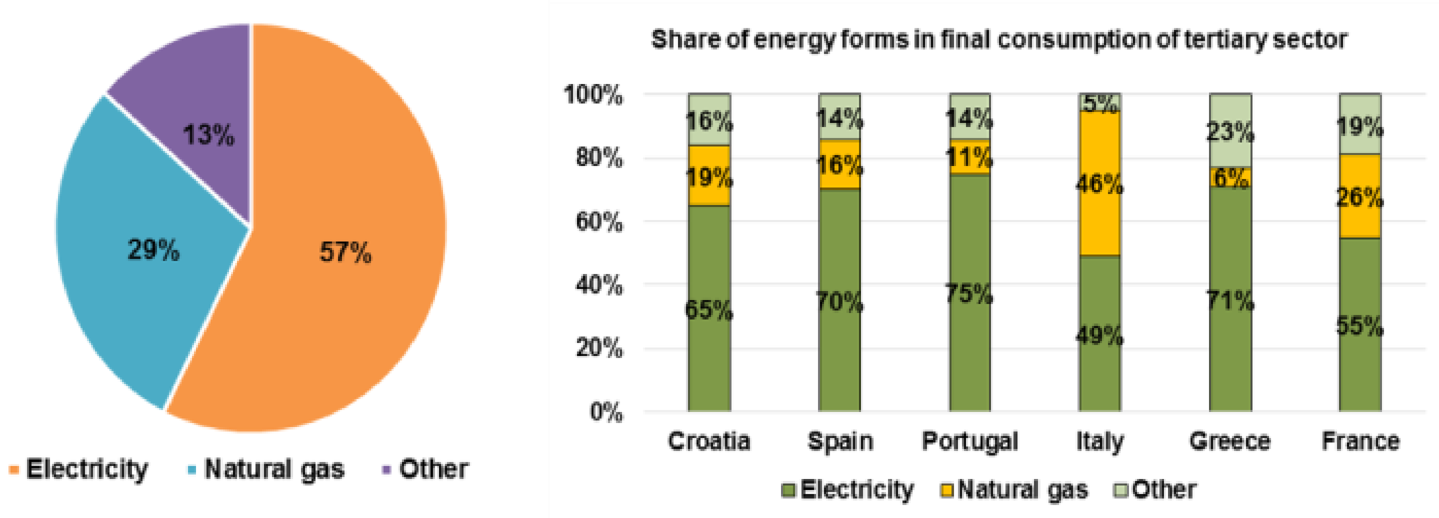


Figure 1 Overall and per country shares of dominantly energy forms in the tertiary sector [14]

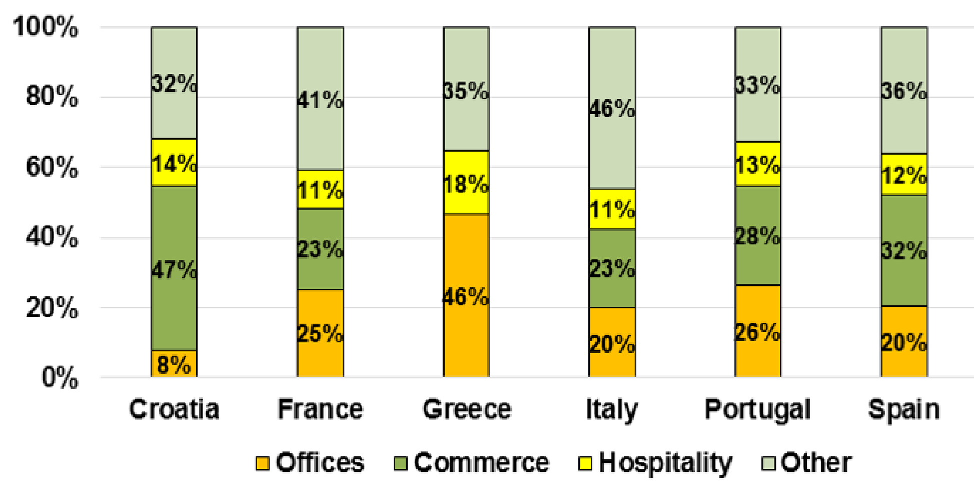


Figure 2 Shares of energy consumption per segment in total final consumption for the 6 countries [14]

Near – Zero Energy Buildings

According to EPBD recast, all new buildings constructed from 31 December 2020 onwards should be implemented as NZEBs, whilst the existing buildings should implement major renovations in order to meet the minimum energy performance requirements. [18]

Energy consumption of NZEBs, according to indicative studies, ranges from 0 to 270 kWh/m^2 of primary energy. The higher values correspond to high energy consumed buildings such as hospitals and non – residential buildings. [18]

Regarding the extended Directions and its recasts from EU Parliament, an important share of State Members has not yet posed the minimum threshold energy efficiency indexes in terms of energy consumption in the national level. According to current status legislation in Southern Europe, Greece and Portugal are included among countries without available national reports and information regarding thresholds for NZEBs. Other countries have their National Plants under implementation providing some information about numerical indicators targets and defining (Portugal, Italy, Spain) while others have already official in place their National Plans including the indicators and corresponding values (Cyprus, France, Estonia). [19,20]

In Cyprus for instance, the threshold for a non-residential NZEB is 125 kWh/m^2/year of primary energy. The majority of collected data refers to residential buildings with a range of 33 to 95 kWh/m^2/year. [21]

Estonia has presented a concrete National Plan for new constructed non-residential buildings, defining the required energy at 100 kWh/m^2/year for office buildings, 130100 kWh/m^2/year for hotel and restaurants, 120kWh/m^2/year for public buildings, 130 kWh/m^2/year for shopping malls, 90 kWh/m^2/year for schools and 270 kWh/m^2/year for hospitals. The Czech Republic set as requirement limit the 90% reduction of primary energy, Bulgaria 30 – 50 kWh/m^2/year, Hungary 60 -115 kWh/m^2/year. [22]

As concerned the existing non – residential buildings, only specific countries have been determined their thresholds values for NZEB such as Belgium (about 108 kWh/m^2/year), Cyprus (125 kWh/m^2/year), Bulgaria (40 – 60 kWh/m^2/year) and Slovenia (100 kWh/m^2/year). [22]

Several studies have been implemented in order to investigate the energy efficient measures towards near zero. Among them included renewable energy technologies, advanced monitoring and control systems, along with high-quality building envelope for implementation in residential, industrial and educational buildings. [23] Among the advanced monitoring and control systems including the Energy Management Systems (EMS) where have been extensively studied since decades in commercial and office buildings, educational buildings, hotels and hospitals, including complexes of buildings. [24]

Current status in Greece

In Greece, the total final consumption amounted to 178,2 TWh in 2013, highlighting a reduction of 30,5% for the period 2007 – 2013. The significant reduction was a result both of implementation of energy efficiency measures and economic downturn of the national economy. [16]

In Greece, the buildings of the tertiary sector are responsible for the 12% of the final energy consumption [15] and according to the Hellenic Statistical Authority, the majority of them are constructed before 1980. [24] The Greek Thermal Regulation was implemented in 1981 with the prescription of limits for U-value and heat transfer for the building envelope.

The 75% of the buildings of the tertiary sector are privately owned. Office buildings and stores are the main market segments followed by hotels, regarding the covering floor area, the corresponding number of buildings in the national level and the primary energy consumption. In table 1 presented the values per type of building use.

Table 1 Number and floor area per type of building use 1[26], 2[27]

Tertiary sector segment	No of buildings	Floor area[1] (m^2, 2012)	Primary energy consumption[2] (TWh)
Hotels	43.516	31.800.000	8,20
Hospitals/Health	1.973	2.390.000	2,15
Schools, Education	21.853	53.200.000	2,19

Offices and stores	206.254	67.300.000	22,71

Health care facilities are the highest energy consumers per unit area reordered 899 kWh/m^2 annual energy consumption as shown in the next figure (Figure 3). Office buildings and stores are following (334,8 kWh/m^2/annually), along with hotels (270,4 kWh/m^2/annually). Schools resulted the lowest consumption in this analysis with 216,7kWh/m^2/annually, remaining though in high levels. [18]

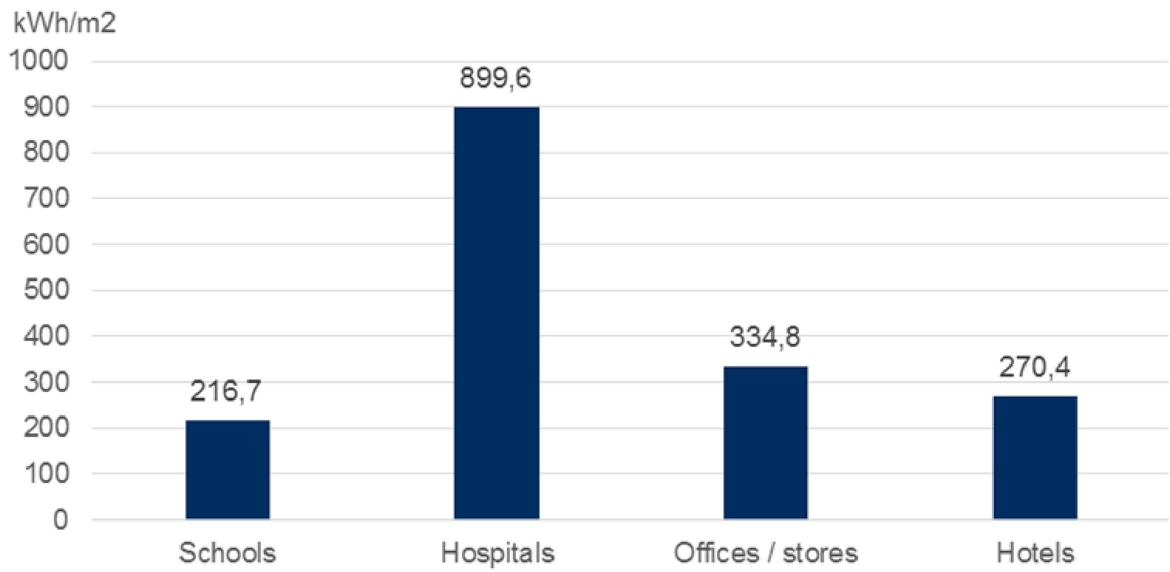


Figure 3 Average energy consumption per building type in Greece[22]

As mentioned above, no threshold for NZEB have been determined through National Plans until today but in 3rd NEEAP, regarding Greece, plans to carry out Energy performance improvements for tertiary sector buildings have been foreseen. More specific, through ESCOs, 3.000 buildings would be renovated during the period 2015 – 2020 according to the National Action Plan. [10]

Chapter 2
Methodology

2.1. Simulations and benchmarking tool

The methodology approach based on the standardization tool developed within the framework of TRUST EPC South initiative, funded by the H2020 EU Programme, targeting to create a common understanding among project actors, facilitate decision – making and unlock the access to project financing by financial institutions.

The benchmarking methodology was applied in order to investigate the potential energy saving through the measures proposed by implementing a standardization method uses an analytical tool called GREPCon (figure 4).

The methodology lies on 3 basic steps:

- Detail energy audit in the structures in order to collect all the available data for a representative model development. Among them are included:
  - Architecture plans
  - Construction materials and fabrics data
  - Energy bills (electricity, gas, oil, biomass)
  - Water bills
  - Operation schedules, occupancy patterns/level
  - Control systems regarding HVAC systems, corresponding set points for heating and cooling, ventilation air flows etc.

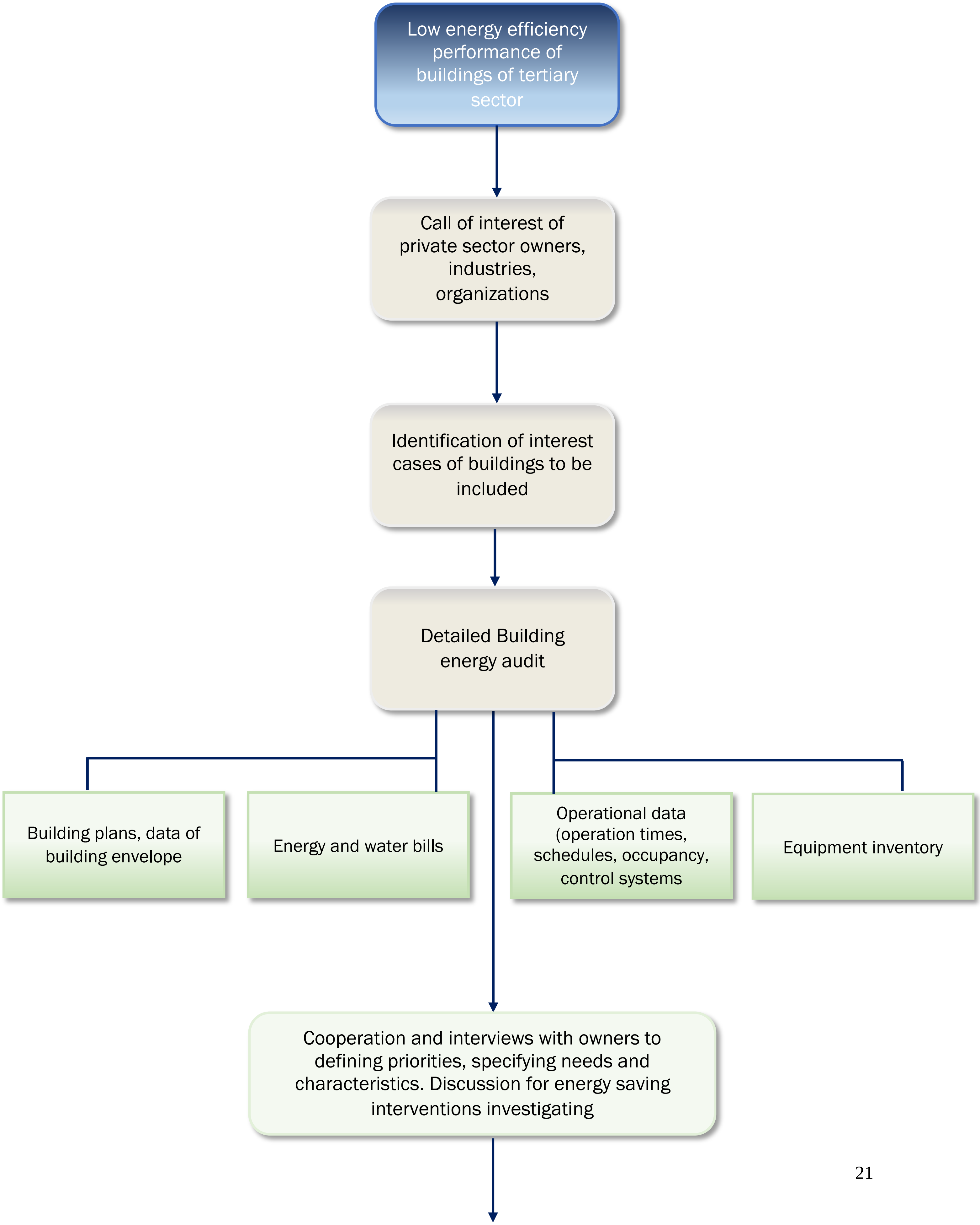
- Thermal simulation of the building through TRNSYS simulation software, for validating of the building construction, having a representative model and applying all the energy saving measures proposed for each case.

- Date collected and inserted in an assessment tool called GREPCon, in order to calculate energy breakdown and savings achieved by the measures examined. An important issue during the apply on standardized GREPCon tool was the evaluation of the building performance through a feasibility rating potential for Energy Performance Contracting. Therefore, specific selected measures were investigated taking also under consideration the owners' preferences.

Having as main aim the investigation of the current situation and the energy saving potential in a variety of buildings of the tertiary sector in Greece in order to become flagship cases for their corresponding sectors, 4 pilot studies were examined as lighthouse examples, representing main segments of tertiary sector buildings: hotel, offices, leisure & sports centre and hospital. The abovementioned methodology was applied in a Resort and Spa Hotel in Crete, one office building in Athens, a large scale hospital in Athens and a leisure and sports canter in Chania.

For the dynamic thermal simulations, the TRNSYS (Transient System Simulation Tool) software was used. The buildings' structure was designed in TNSYS3D plugin for SketchUp, taking into account the geometry, construction materials, operational schedules, set points for HVAC systems, etc, as they defined from architecture plans, energy bills and data collection.

The key step of the methodology followed was the close cooperation with owners and personal interviews of facility staff in order to record also the occupants' opinions, along with owners' preferences and priorities regarding the energy saving interventions would have been included.


Low energy efficiency performance of buildings of tertiary sector
Call of interest of private sector owners, industries, organizations
Identification of interest cases of buildings to be included
Detailed Building energy audit
Building plans, data of building envelope
Energy and water bills
Operational data (operation times, schedules, occupancy, control systems
Equipment inventory
Cooperation and interviews with owners to defining priorities, specifying needs and characteristics. Discussion for energy saving interventions investigating

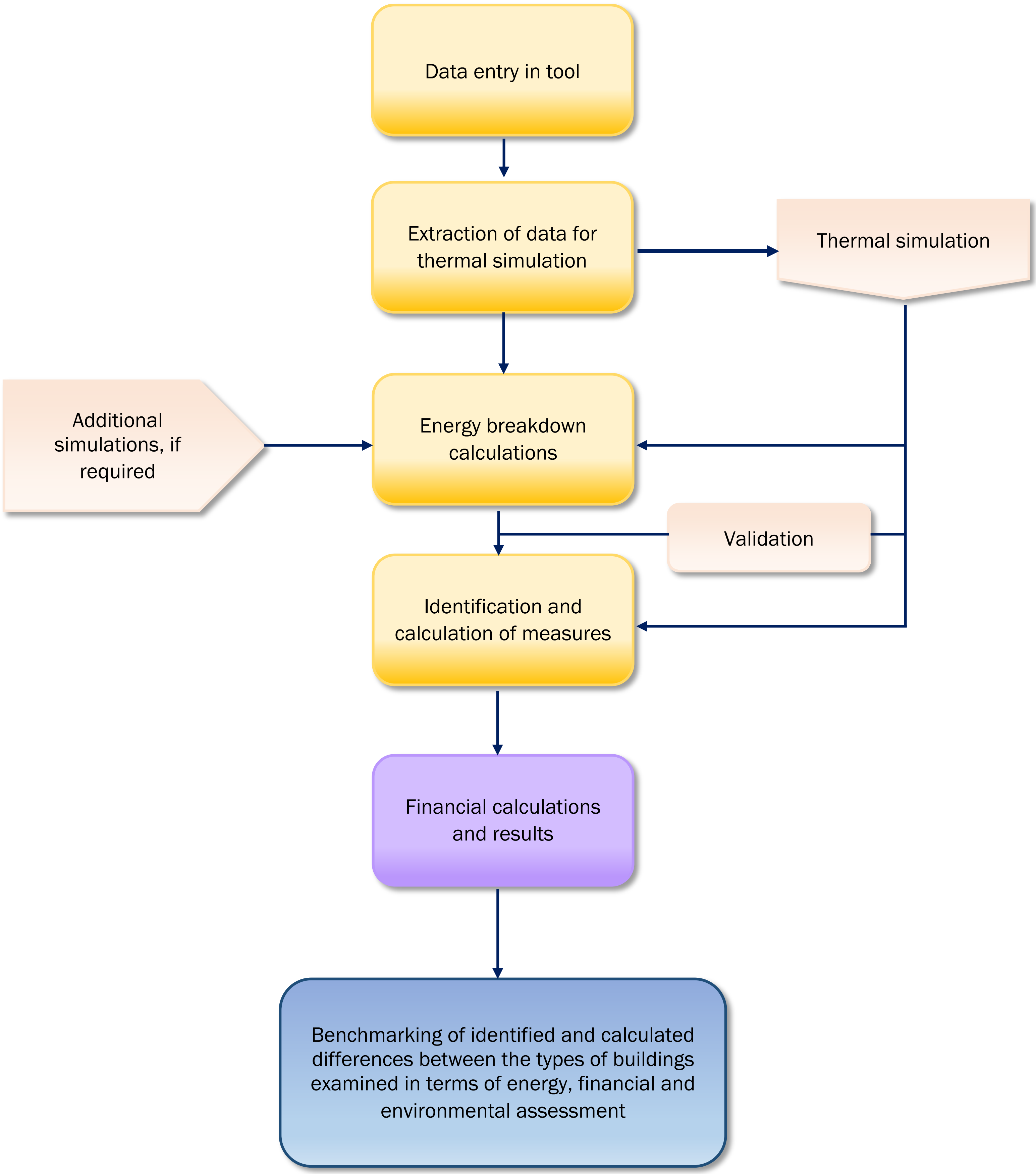


Figure 4 Steps of the methodology followed

It should be mentioned that according to GREPCon tool requirements, only the operational set points for cooling and heating (depending on occupancy schedules of each building) were required and inserted in TRNBuild. Technical characteristics and specifications of heating, cooling and ventilation systems were not defined within the TRNSyS but inserted directly in GREPCon Tool along with other segments of the operational system such as lighting, pumps, energy consumptions of buildings' subsections: restaurants, kitchens, conference rooms, gyms, swimming pools etc.

Assumptions were necessary to defined in order to determine efficiently the occupancy schedules, especially in cases such as hotels, hospitals and sports centres. The assessment for inserted occupancy schedules was based on collected data, with average occupancies in hotel common spaces to be assumed. As concerned the corresponding occupancy schedules for office buildings, it was easily determined according to working schedule hours.

Validation of the simulated buildings was done against collected energy bills for electricity, natural gas, oil, LPG in order to identify the total energy consumption of each pilot project. Heating and cooling needs have to be exported from simulations within 10% accepted difference to the ones calculated by the tool, in order to develop a representative model and the energy efficiency interventions to be satisfactorily rendered. Calculation of energy savings from investigated measures was necessary for the determination of financial assessment results.

The methodology based on benchmarking assessment for a variety of buildings of the tertiary sector, in order to appraise the feasibility of the installation of energy saving measures, gathering the most important results regarding the investigated measures separately. An important step of the methodology is the parallel financial assessment of the measures.

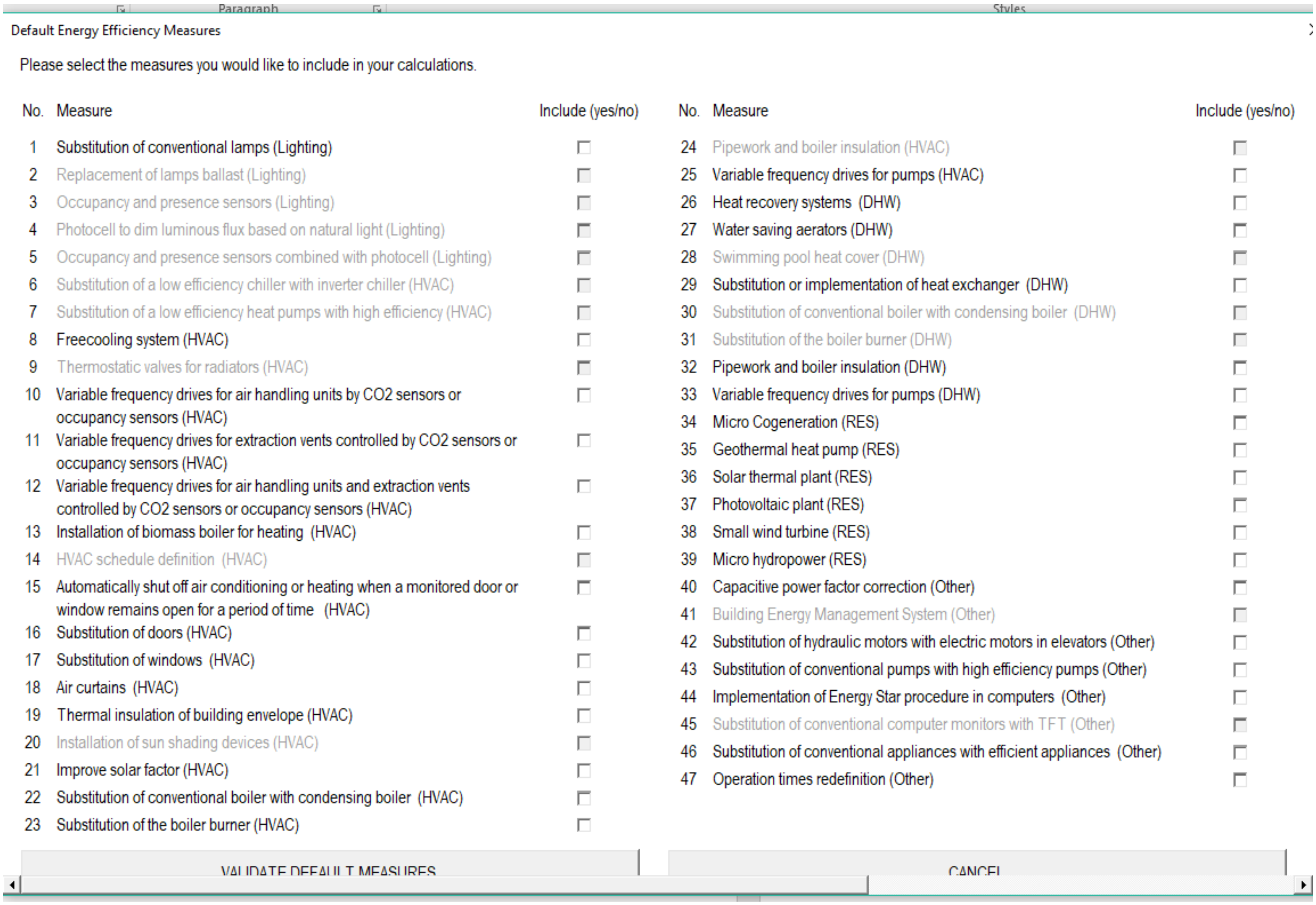
A list of 47 energy saving measures is available during the study of each pilot project, giving the auditor the opportunity to decide regarding the most suitable intervention for each case within the analytical GREPCon tool. The measures list includes a number of passive interventions (insulation of building envelope, substitution of windows, doors and other interventions regarding the building structure upgrade), active systems (substitution of conventional lamps, sensors, boilers etc), renewables etc.

In table 2 presented all the available standardized measures in GREPCon. Depending on inserted data and simulation results, a number of measures proposed directly from the tool as the identified potential interventions but the user has always the opportunity to choose any of the 47 measures prefers, additionally.

Table 2 List of 47 standardized measures in GREPCon Tool

GREPCon Available Energy Efficiency Measures		
No.	**System**	**Intervention**
1	Lighting	Substitution of conventional lamps
2		Replacement of lamps ballast
3		Occupancy and presence sensors
4		Photocell to dim luminous flux based on natural light
5		Occupancy and presence sensors combined with photocell
6	HVAC	Substitution of a low-efficiency chiller with inverter chiller
7		Substitution of low-efficiency heat pumps with high efficiency
8		Freecooling system
9		Thermostatic valves for radiators
10		Variable frequency drives for air handling units by CO_2 sensors or occupancy sensors
11		Variable frequency drives for extraction vents controlled by CO_2 sensors or occupancy sensors
12		Variable frequency drives for air handling units and extraction vents controlled by CO_2 sensors or occupancy sensors
13		Installation of a biomass boiler for heating
14		HVAC schedule definition
15		Automatically shut off air conditioning or heating when monitored door or window remains open for a period of time
16		Substitution of doors
17		Substitution of windows
18		Air curtains
19		Thermal insulation of building envelope
20		Installation of sun shading devices
21		Improve solar factor
22		Substitution of a conventional boiler with a condensing boiler

23		Substitution of boiler burner
24		Pipework and boiler insulation
25		Variable frequency drives for pumps
26	DWH	Heat recovery systems
27		Water saving aerators
28		Swimming pool heat cover
29		Substitution or implementation of the heat exchanger
30		Substitution of a conventional boiler with a condensing boiler
31		Substitution of boiler burner
32		Pipework and boiler insulation
33		Variable frequency drives for pumps
34	RES	Micro Cogeneration
35		Geothermal Heat Pump
36		Solar thermal plant
37		Photovoltaic plant
38		Small wind turbine
39		Micro-hydropower
40	Other	Capacitive power factor correction
41		Building Energy Management System
42		Substitution of hydraulic motors with electric motors in elevators
43		Substitution of conventional pumps with high-efficiency pumps
44		Implementation of Energy Star procedure in computers
45		Substitution of conventional computer monitors with TFT
46		Substitution of conventional appliances with efficient
47		Operation times redefinition


Default Energy Efficiency Measures

Please select the measures you would like to include in your calculations.

No.	Measure	Include (yes/no)
1	Substitution of conventional lamps (Lighting)	
2	Replacement of lamps ballast (Lighting)	
3	Occupancy and presence sensors (Lighting)	
4	Photocell to dim luminous flux based on natural light (Lighting)	
5	Occupancy and presence sensors combined with photocell (Lighting)	
6	Substitution of a low efficiency chiller with inverter chiller (HVAC)	
7	Substitution of a low efficiency heat pumps with high efficiency (HVAC)	
8	Freecooling system (HVAC)	
9	Thermostatic valves for radiators (HVAC)	
10	Variable frequency drives for air handling units by CO2 sensors or occupancy sensors (HVAC)	
11	Variable frequency drives for extraction vents controlled by CO2 sensors or occupancy sensors (HVAC)	
12	Variable frequency drives for air handling units and extraction vents controlled by CO2 sensors or occupancy sensors (HVAC)	
13	Installation of biomass boiler for heating (HVAC)	
14	HVAC schedule definition (HVAC)	
15	Automatically shut off air conditioning or heating when a monitored door or window remains open for a period of time (HVAC)	
16	Substitution of doors (HVAC)	
17	Substitution of windows (HVAC)	
18	Air curtains (HVAC)	
19	Thermal insulation of building envelope (HVAC)	
20	Installation of sun shading devices (HVAC)	
21	Improve solar factor (HVAC)	
22	Substitution of conventional boiler with condensing boiler (HVAC)	
23	Substitution of the boiler burner (HVAC)	
24	Pipework and boiler insulation (HVAC)	
25	Variable frequency drives for pumps (HVAC)	
26	Heat recovery systems (DHW)	
27	Water saving aerators (DHW)	
28	Swimming pool heat cover (DHW)	
29	Substitution or implementation of heat exchanger (DHW)	
30	Substitution of conventional boiler with condensing boiler (DHW)	
31	Substitution of the boiler burner (DHW)	
32	Pipework and boiler insulation (DHW)	
33	Variable frequency drives for pumps (DHW)	
34	Micro Cogeneration (RES)	
35	Geothermal heat pump (RES)	
36	Solar thermal plant (RES)	
37	Photovoltaic plant (RES)	
38	Small wind turbine (RES)	
39	Micro hydropower (RES)	
40	Capacitive power factor correction (Other)	
41	Building Energy Management System (Other)	
42	Substitution of hydraulic motors with electric motors in elevators (Other)	
43	Substitution of conventional pumps with high efficiency pumps (Other)	
44	Implementation of Energy Star procedure in computers (Other)	
45	Substitution of conventional computer monitors with TFT (Other)	
46	Substitution of conventional appliances with efficient appliances (Other)	
47	Operation times redefinition (Other)	

Figure 5 *Depiction of the measures in the GREPCon Tool*

2.2. Description of Pilot Cases

The investigated cases were included in this study as the most representative cases in terms of energy market needs as described before in the state of the art and the most interest in terms of energy efficiency measures implementation and energy analysis. As the market results shown, offices, accommodation facilities and hospitals are on the top of the list with higher energy consumers in Greece, presenting, therefore, a great interest and potential for energy saving measures.

Therefore, a Resort and Spa Hotel in Lasithi, an Office building in Athens, a Leisure and Sports Centre in Chania and a Maternity and Paediatric Clinic in Athens, were selected to studied and presented as the most replicable of high consumer cases in national level, according to national market analysis.

2.2.1. Resort Hotel & Spa, Lasithi, Crete

The 15 buildings complex hotel in non – urban location in Crete has 18.000 m^2 total size and includes rooms and suites for more than 1.000 guests, 3 restaurants, bars, disco, indoor – heated swimming pool and outdoor pools, spa centre and kids club. The main energy sources are electricity and biomass, while oil and solar energy contribute also to overall energy needs.

Its total current annual consumption is 2.082.017 kWh/year, and the corresponding energy costs account for 320.629 €/year.

The accommodation has applied ISO 14001:2004 (revised by 14001:2015) and achieved Travelife Gold Certification for sustainability in Tourism.

Among the energy-saving interventions examined included substitution of conventional lamps with LED lamps, substitution of the 300 A/C split units for rooms cooling with heat pumps along with heat recovery system installation, substitution of window frames with thermal-break aluminium frames, double glazing, heat cover for the indoor swimming pool, solar thermal plant installation for DHW, thermal insulation on specific parts of buildings complex envelope and PV plant installation.

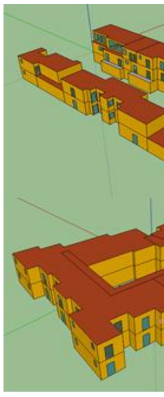


Figure 6 Resort and Spa Hotel in Sissi, Lasithi, Crete
Real structure (left), SketchUp design (right)

2.2.2. Office building in Athens

The 8-floor and 5 underground parking floors building is located on one for the most visited and crowded avenues in Athens. It has built in 2008 following a bioclimatic architecture method according to energy efficiency directions and has also applied EN ISO 50001:2011. Among the special features of the building included the high percentage of glass in the façade and the glass atrium from the ground floor until the 4th floor. The main energy sources are electricity for cooling, lighting, electrical devices and other systems, and natural gas for heating.

The total energy consumption is 942.554 kWh/year, and the corresponding energy costs are 105.960 €/year.

The building is characterized as high energy efficient due to bioclimatic design and the already implemented energy saving measures, consisting, therefore, a challenge for additional energy saving measures examined. The measures included substitution of conventional lamps, variable frequency drives for AHU by CO_2 sensors, improve solar factor by installing low emissivity

window films, solar thermal plant and photovoltaic plant installation.

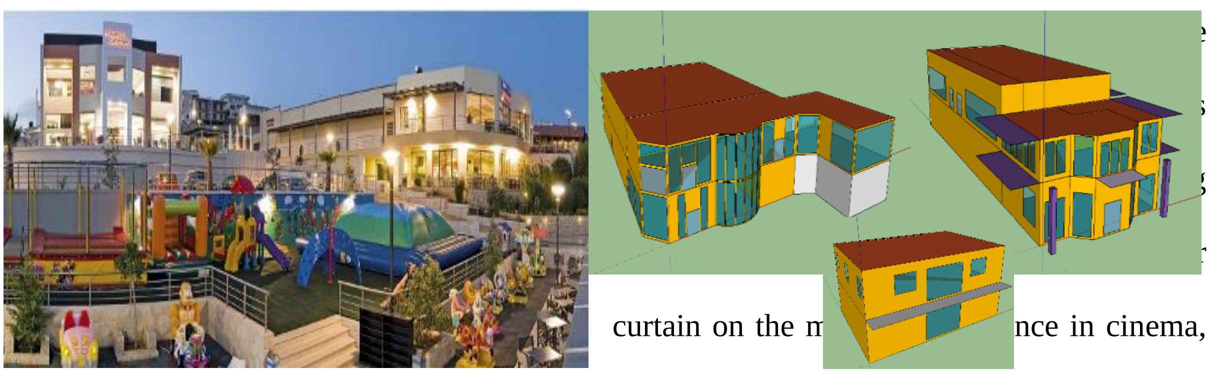
Figure 7 Office building in Athens
Real structure (left), SketchUp design (right)

2.2.3. Leisure & Sports Centre in Chania, Crete

The 3 buildings complex was built in 2003 and is located in the non-urban area of the city. The facility of 4.172 m^2 includes bowling, cinemas, pastry and catering factory and kids' leisure outdoor facilities. It has annual, daily operation and the only energy source is electricity, with heating and cooling being the main consumption items.

The current total consumption of the facility on annual base is 862.200 kWh and the corresponding energy costs account for 154.506 €/year.

The owner has already implemented some energy saving interventions such as substitution of all lamps of the facility with LED lamps and



curtain on the m nce in cinema, installation of window films on south windows in order to improve solar factor, occupancy and presence sensors installation in WCs, substitution of windows and photovoltaic plant installation.

Figure 8 Leisure & Sports Centre, Chania, Crete
Real structure (left), SketchUp design (right)

2.2.4. Hospital in Athens

The 2 underground-connected buildings complex located in the city centre, on central avenue. The main building, an 8-floors and 3 undergrounds building, has constructed in 1994, while the children's department added in 2004. The total size of the facility is 45.000 m^2, with 850 occupiers as permanent staff and daily operation, 24/7. The facility has applied ISO 9001:2008 for Quality Management system along with Environmental Management System for rational use of energy, water and resources, medical waste management and environmental protection.

The current total consumption reaches at 19.411.465 kWh/year, and annual energy costs account for 1.653.575 €/year.

Within the facility have already applied several energy saving solutions on building the structure, the equipment and the operation modes (such as BMS, LED lamps, shading devices, substitution of windows etc.). Heating and cooling spaces along with medical and laboratory equipment are the main energy consumption items. The measures examined are the substitution of the conventional boiler for DHW with condensing boiler, installation of window films, heat recovery system and photovoltaic plant.

Figure 9 Maternity and Pediatric Clinic in Athens
Real structure (left), SketchUp design (right)

Table 3 Characteristic of the 4 pilot cases

Studied Cases				
Sector	**Resort & Spa Hotel**	**Office in Athens**	**Leisure & Sports center**	**Hospital**
Size	18.018 m^2	6.575 m^2	4.172 m^2	45.000 m^2
Year of construction	First 3 buildings in 1990, rest gradually added until 2000	2008 Bioclimatic architecture	2003	Maternity Clinic 1994, Children Clinic 2004
Total Energy consumption (kWh /year)	**2.082.017**	**942.554**	**862.200**	**19.411.465**
Total primary energy consumption (kWh /year)	4.624.200	2.469.599	2.500.380	39.015.250
Actual Energy Consumption (kWh/m2/yr)	**115,6**	**143**	**207**	**431**
CO_2 emissions ($kgCO_2eq/m^2/yr$)	77	123	204	340

The proposed measures and the evaluation on financial and energy saving base, are presented in the next chapter.

Chapter 3
Results

The investigated pilot buildings are representative cases of each category: hotels, offices, healthcare facilities, leisure centres. Office buildings have an annual use, small and medium scale hotels provide common services for residents during summer vacations, the hospital is a representative case of 24/7 operation building and the leisure centre provides a number of characteristic activities such as cinema and other entertainment and sports activities, indoors and outdoors.

In the case of hotels, seasonality has a significant impact for general application of energy efficiency measures due to the half energy savings gaining, in order to deliver the corresponding financial savings and give a proper payback time. In the case of offices, occupants' needs and preferences are extremely important for the total building energy performance. In addition, the 4 pilots located in cities in central and south Greece; in the region of Crete and Athens, representative locations with Mediterranean climate conditions, characterized by mild winters and hot summers.

3.1. Simulation results

TRNSYS simulation software was used for simulation of the buildings. According to collected data and designs, were created the corresponding buildings drawings in TRNSYS3D plugin for SketchUp, taking into account specifications and geometry for each case. As described in methodology, only heating and cooling needs were necessary to calculated from the simulation software, taking under consideration occupancy schedules of each facility, set points for temperatures and operation schedules.

Validation of the models is done against the energy bills and invoices.

Regarding the hotel, the hospital and the leisure centre, they were complexes of building and the total energy consumption on the facilities was not sub-metered per building. Each case was investigated as a single project in order to have the corresponding energy needs for validation against the bills. The case of the office building was obviously a simpler study as a single structure.

The real picture and the corresponding simulation designs are presented in the next figures (10-12). Regarding the hotel, only cooling needs were calculated from TRNSYS during its summer operation time.

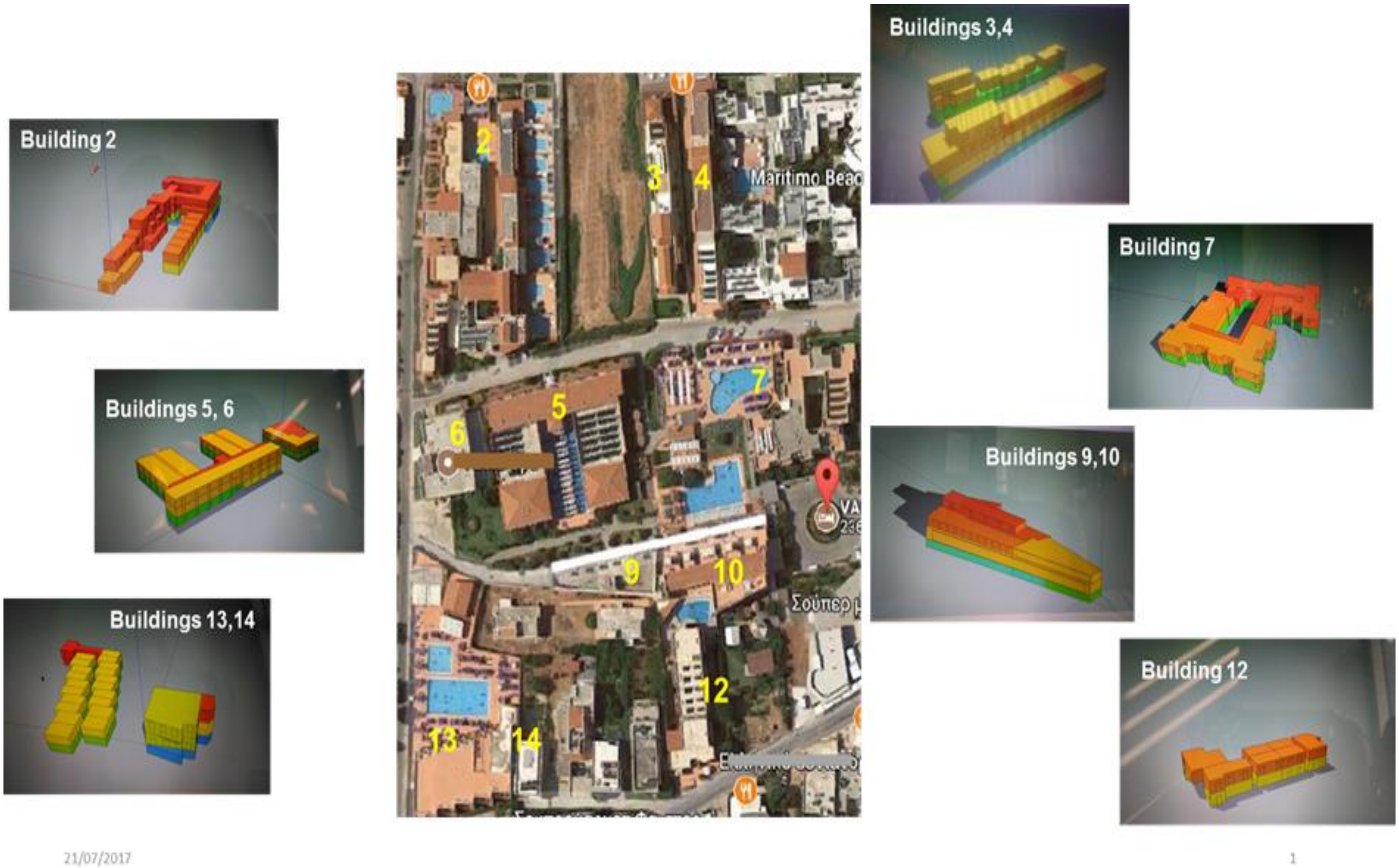


Figure 10 Vasia Resort and Spa Hotel, Sissi, Lasithi, Crete

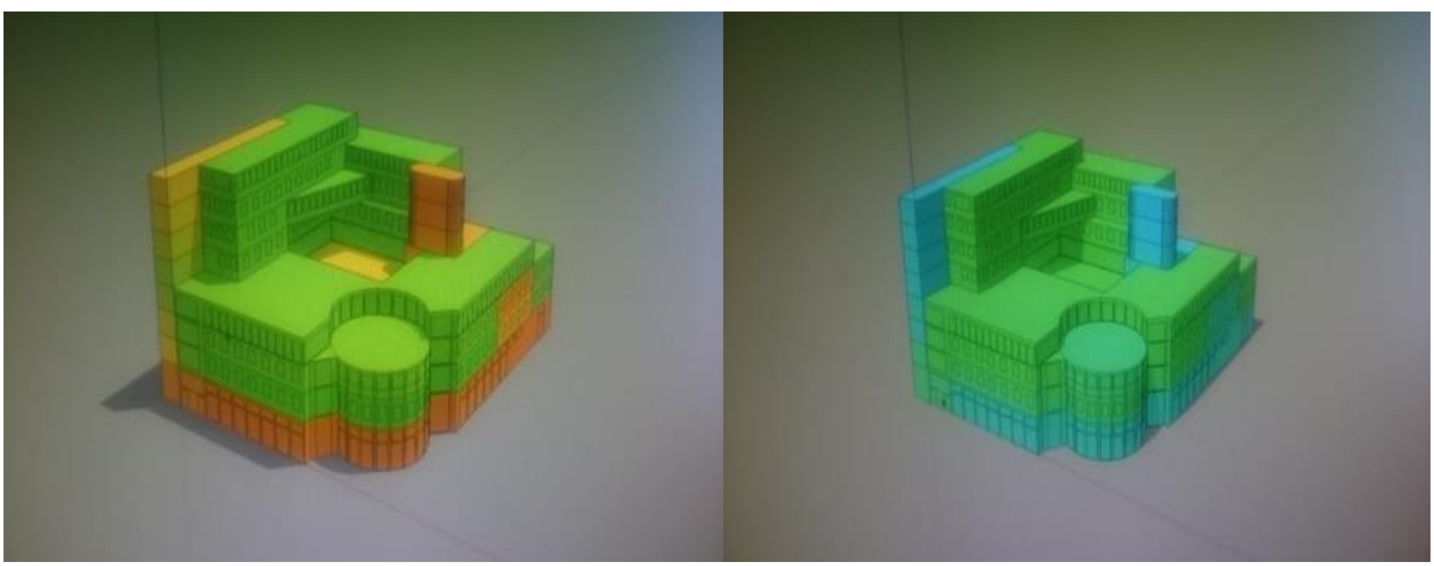


Figure 11 Regulatory Authority of Energy office building, Athens

Heating loads on the left picture, cooling loads on the right

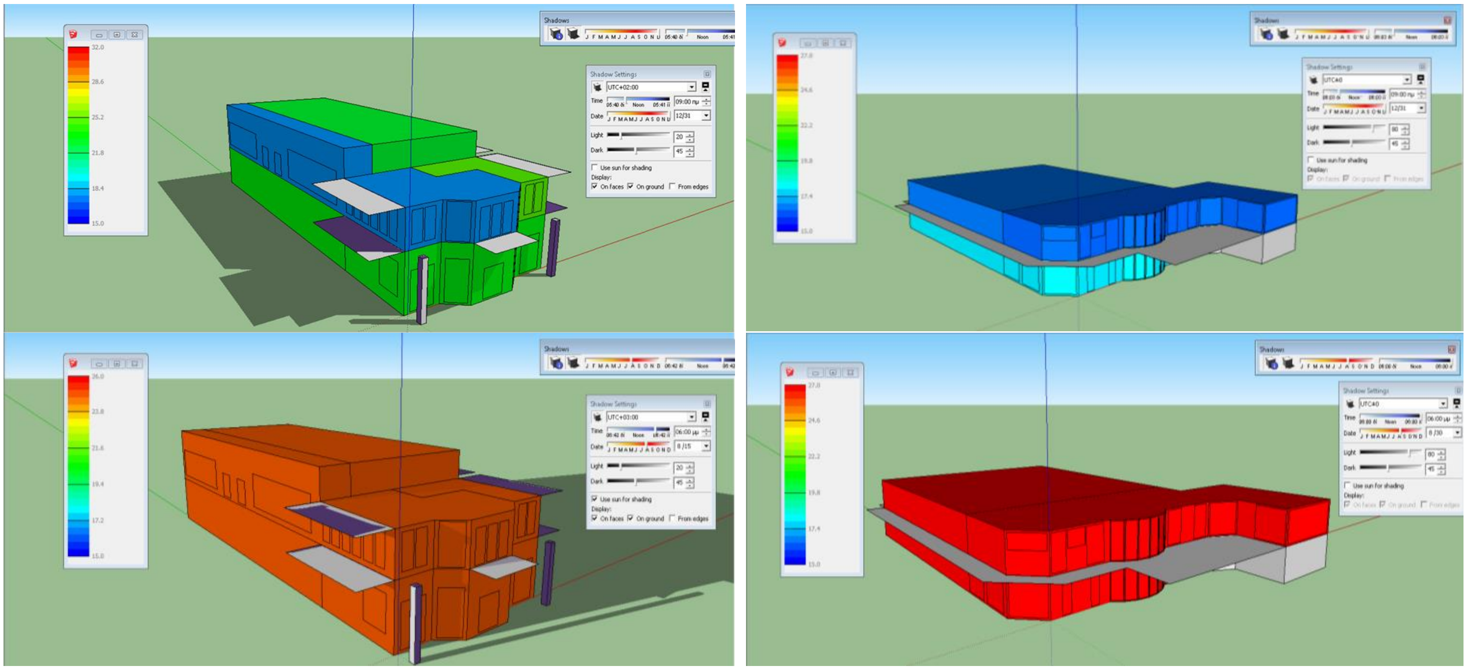


Figure 12 Leisure and Sports Centre, Bowling and Cinema buildings, Chania, Crete
Cooling loads on the upper pictures, heating loads on the bottom

3.2. Breakdown Results

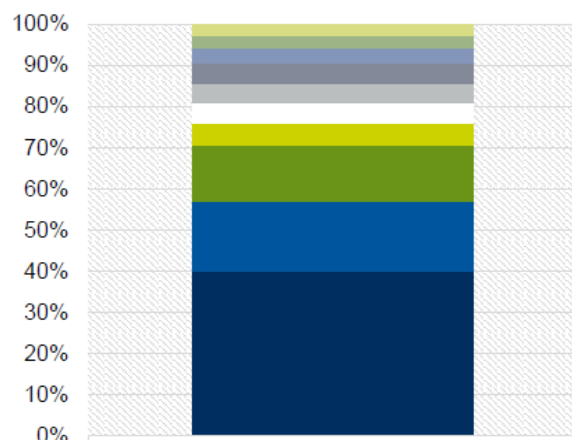
An annual energy breakdown in kWh per year was exported from the tool for each pilot case, highlighting the most energy consumer segment within the facility. The exported results were a guide in order to point out the higher consumption sources and proposed consequently the appropriate energy saving interventions. The followed figures are shown the results.

3.2.1 Resort & Spa Hotel in Lasithi

The 15-buildings complex in Lasithi has a total consumption of 2.082.017 kWh/year. The corresponding annual costs account for 320.630 €/year and the emissions at 1.381.005 kgCO_2eq/year. The currently annual facility consumption is 115,6 kWh/m^2.

The main energy consumption item, in this case, is the cooling demand for indoor spaces: rooms, restaurants, bars, disco and the other common spaces. The annual cooling needs account for about 780 MWh (38,4%). DHW production comes both from biomass and oil, the total needs calculated at 21% - 16% from biomass and 5% of the oil. Lighting and auxiliary systems such as pumps have an important share (5% - 100 MWh and 4,7% - 98 MWh respectively). Consumption of other facilities, restaurants, spa, heated pool, complete the hotel performance with lower consumptions as presented in Figure 14.

Substitution of the existing cooling system (300 A/C split units), upgrade of the DHW system and installation of solar thermal plant and substitution of lamps, are included among the examined measures.



	Consumption (kWh/y)
Spa (biomass)	54.250
Restaurant (biomass)	60.885
Spa (electricity)	68.510
Restaurant (electricity)	95.789
Auxiliaries (electricity)	96.033
DHW (oil)	98.472
Lighting (electricity)	100.031
Restaurant (gas)	270.794
DHW (biomass)	334.182
Cooling (electricity)	779.740

Figure 13 Energy breakdown of Resort & Spa Hotel in Lasithi

3.2.2. Office Building in Athens

The Office building total consumption reaches at 942.500 kWh/year, annual energy costs account for 105.690 € and associated emissions at 811,494 $kgCO_2eq$/year. The facility consumption is 143,4 kWh/m^2 per year.

Server rooms required the majority of energy which is quite a logical result considering the type of services hosted in (Regulatory Authority of Energy). The corresponding energy consumption is 238.280 kWh/year (25,3% of total). Heating (gas) and cooling (electricity) are followed resulting about the same amount of energy (169 MWh/y & 162 MWh/y respectively). Lighting (15,7%), ventilation (7%), auxiliary systems (6,8%), IT (4,2%), parking (4%), elevators (1,5%) DHW (0,6%) and external lighting (0,2%) completed the overall breakdown of the building.

It should be considered the ISO applied for the efficient management of energy consumption within the building, and the bioclimatic architecture as well. Therefore, the HVAC consumptions are not significantly high considering the type of building. Even though the already implemented measures for ene ntional lamps, variable frequenc low – e (low emissivity) films, n.

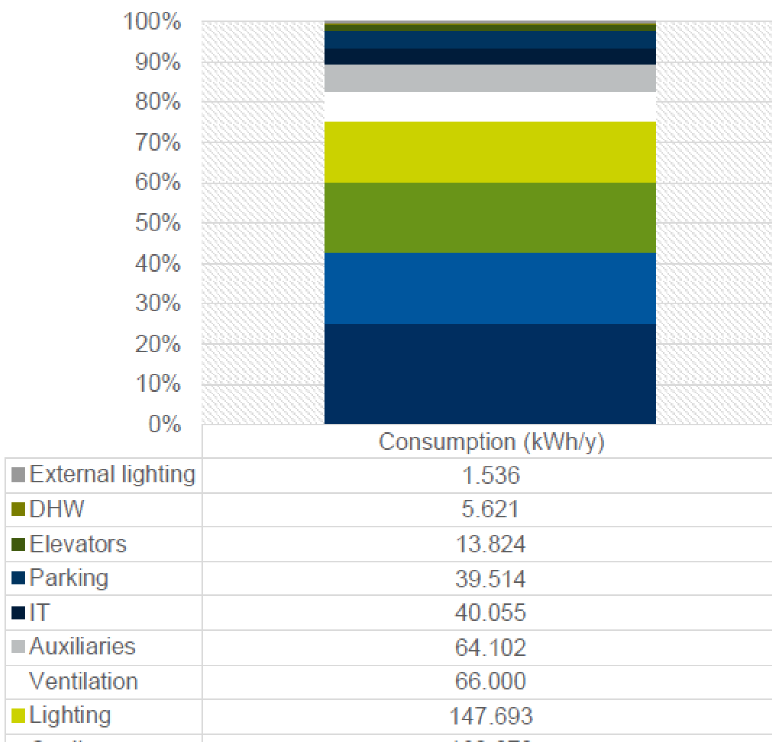
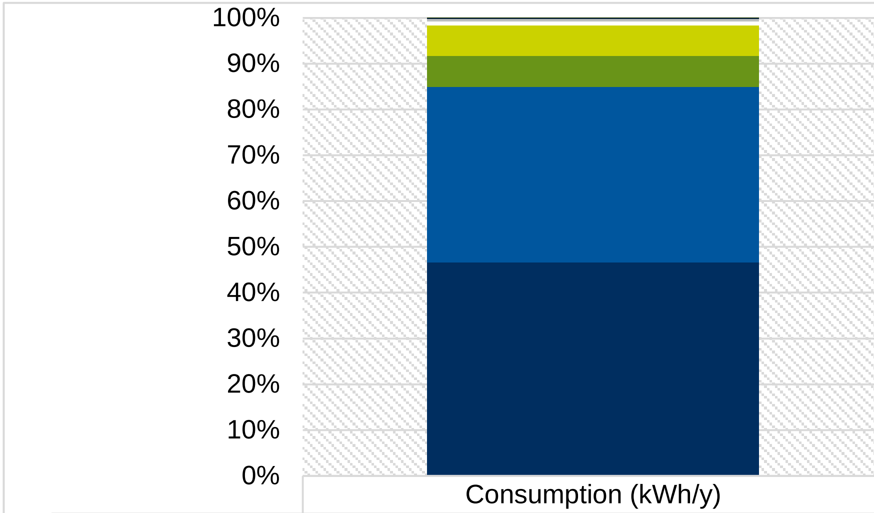


Figure 14 Energy breakdown of Office building in Athens

3.2.5. Leisure and Sports centre in Chania

The three buildings complex leisure and sports centre have an annual consumption of 862.200 kWh/year - 206,7 kWh/m^2. Considering the orientation of the buildings and the Mediterranean climate of the location, cooling to has the majority of consumed energy (46%, 402.307 kWh/year). Up next is heating (38,2%) followed by lighting (7%), training and leisure equipment (6,7%) and elevators (1%). The energy consumption for lighting is significantly low considering the type of building and its daily, annual use due to the substitution of conventional lamps with LED lamps within the two main buildings (cinema & bowling). The resulted consumption for ventilation mentioned on breakdown diagram refers to an autonomous auxiliary system for one single space ventilation in the bowling building, not covering properly the corresponding ventilation needs.

Due to the orientation of the buildings and the non – efficient management and operation of the heating and cooling system, the measures proposed were included substitution of heating and cooling system, air curtains for the permanently open main entrances, low – emissivity window films installation on south windows and photovoltaic plant installation.



	Consumption (kWh/y)
Auxiliaries	155
Ventilation	393
Other	967
External lighting	5.242
Elevator	6.698
Training & Leisure Equipment	57.658
Lighting	59.466
Heating	329.252
Cooling	402.307

Figure 15 Energy breakdown of Leisure and Sports Centre in Chania

3.2.6. Hospital in Athens

The 45.000m^2 buildings complex in Athens (Maternity and Pediatric Clinic), has extremely high energy consumption compare to the rest 3 pilot cases but it is an expected result as it refers to a 24/7 operation hospital. The total consumption of energy is about 19,5 GWh/y, about 456 kWh/m^2 per year. The resulting total energy consumption per m^2 (456 kWh/m^2) highlighting the energy efficiency of that hospital and the several energy interventions have already implemented, comparing the average corresponding value for those types of building arise from the national market inventory (899,6 kWh/m^2). The corresponding energy costs account for over 1,6 million euros on annual base and the associated emissions are 4,317,772 kgCO_2eq/year.

As expected, heating, cooling and ventilation are on the top of energy consumption items list, a logical result considering the type of the building and the providing services. Medical and laboratory equipment has also significant consumed energy. More specific, cooling consumption is the 33,6% of the total energy (about 6,5 GWh/year), heating the 28% (about 5,5 GWh/year) and ventilation the 10,5% (2 GWh/year). A 10,5% refers also the corresponding equipment consumption, followed by the elevators (5%), domestic hot water production (3,4%), lighting (3,1%) and cooling towers (about 3%). The low percentage of lighting consumption is a result of the total substitution of conventional lamps with LED lamps within the 2 buildings.

The IASO Group has implemented so far a number of efficient measures for energy saving including LED lamps installation, substitution of oil burners with natural gas, installation of double glazed thermal break aluminium window frames, Building Management System for energy efficiency and other. Therefore, an important amount of energy has already saved. The interest, in this case, was the proposal additional energy-saving measure. Substitution of the conventional boiler for DHW with condensing boiler, installation of low emissivity window films, heat recovery system and photovoltaic plant adopted on the parking free space, were examined.

The detailed results of the examined measures of each pilot case are presented in the next section.

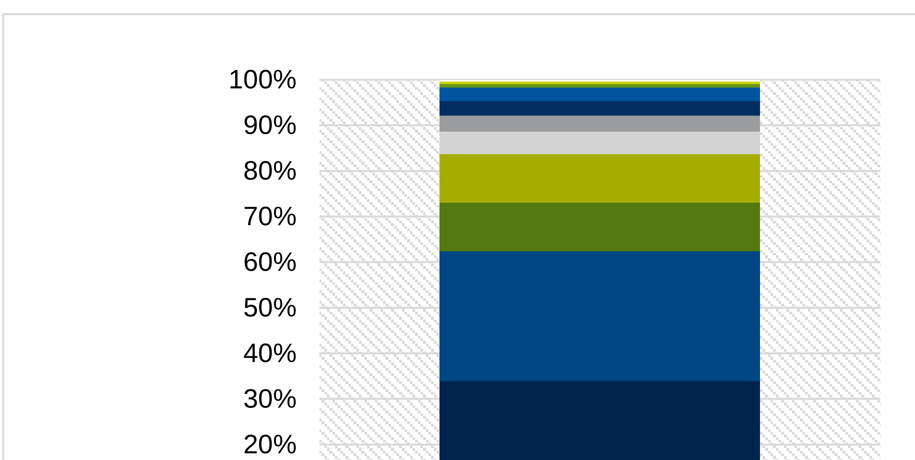


Figure 16 Energy breakdown of the Maternity and Pediatric Clinic in Athens

3.3 Examined measures – Technical & Financial Analysis

Considering the problems identifying through energy auditing, the owners' preferences and priorities regarding energy saving interventions, the results of simulations and the energy breakdown as it exported from GREPCon tool, a number of specific interventions came out and studied in order to be examined.

3.3.1. Resort & Spa Hotel in Rethymno

Several interventions for energy saving had already implemented in Vasia Sentido Resort & Spa Hotel in Sissi village in Lasithi such as aluminium thermal break window frames in new buildings of the facility, solar thermal for DWH covering though only a little part of accommodation's needs, installation of biomass burner for domestic hot water needs and indoor heated pool and spa needs.

As mentioned before, the hotel has developed a general environmental policy by applying of ISO 14001:2004 (revised by 14001:2015) and has also achieved Travelife Gold Certification for sustainability in Tourism. The further reduction of its energy consumption is a target goal for the owners.

Therefore, several energy interventions were proposed and examined for this facility in order to become a near zero energy hotel. Substitution of the conventional lamps with LED lamps in overall the facility has shown a satisfaction saving of 42.324 kWh/year, corresponds to 5.860€ annual savings.

The accommodation has several types of energy sources such as electricity, biomass, oil, LPG, solar energy. The new buildings constructed, were gradually added to the total facility through the years while installing separately cooling and DHW systems. They were not designed to cover the total energy needs of the accommodation. Therefore, a number of combined interventions proposed but examined and presented separately: installation of 50 heat pumps systems connected with the 300 split AC units in the rooms and the 10 additional outputs in common spaces. The specific systems provide also heat recovery system in order to exploit the wasteful heat that escapes into the atmosphere. The savings of this intervention reach the 390.000 kWh/year and corresponding financial savings are calculated at 54.000€ per year. Heat recovery systems could provide an additional amount of 294.500 kWh/year and 19.145€ additional savings.

During the energy audit and taking under consideration the simulation results were noticed extremely high temperature and uncomfortable conditions within the buildings 9 and 10 in which hosted the main restaurant. The high percentage of glazing in the façade was the main characteristic, therefore, it was examined as an additional measure the substitution of single glazed metallic window frames with low emissivity double glazed windows and thermal break aluminium frames, achieving 47.500 kWh/year savings only in this specific structure. Thermal insulation on the building envelope was also examined for the same buildings resulting a 2,3% of the total of additional savings.

As concerned the indoor heated pool, the purchase of a heat cover could provide 1,3% savings of total energy consumption, saved about 27.200 kWh/year. The installation of the solar thermal plant was also examined resulting 7,3% savings from DHW consumption for the accommodation. Last but not least, the installation of a 50 kWp PV plant was also investigated, resulted 3,6% energy savings, corresponding to more than 10.000€ in financial savings per year.

The total amount of savings achieved is over 1 GWh/year, reducing by over the half of the total consumed energy (55,8 kWh/m^2 from 115,6 kWh/m^2). Regarding financial savings, the total amount of 114.288€ is saved per year which represent the 35,6% of the annual operating costs for the facility. The total investment of the proposed measures calculated at 596.500€, giving a payback period of 5,2 years.

The SME (Small and Medium-sized Enterprises) hotels are representing the 90% of the hotel sector in the European Union. Therefore, the results from the methodology could be easily and efficiently replicable by other hotels, especially within the same climate zone.

Table 4 Financial and energy saving results for each measure examined - Resort and Spa Hotel in Lasithi

ESM Recommendation	Savings [kWh/year]	% Energy Savings	Savings [€/year]	% Financial savings	Investment [€]	Simple Payback

						[years]
Substitution of conventional lamps	42.324	2,0	5.862	1,8%	18.176	3,1
Installation of heat pumps	390.073	18,7	54.025	16,8%	250.000	4,6
Substitution of windows	47.508	2,3	6.580	2,1%	32.305	4,9
Thermal insulation of building envelope	47.507	2,3	6.580	2,1%	67.991	10,3
Heat recovery systems	294.540	14,1	19.145	6,0%	50.000	2,6
Swimming pool heat cover	27.208	1,3	1.802	0,6%	10.500	5,8
Solar thermal plant	152.413	7,3	9.907	3,1%	110.000	11,1
Photovoltaic plant	75.000	3,6	10.388	3,2%	57.500	5,5
TOTAL	**1.076.573 kWh/year** **55,8 kWh/m^2**	**52%** of total consumption	**114.288**	**35,65%** of total yearly costs	**596.472**	**5,2**

3.3.2. Office Building in Athens

The specific building was quite challenging due to its current energy efficiency performance. As mentioned before, the building has been constructed following bioclimatic design principles, applies ISO 50001 certification and BMS for efficient energy management.

Despite all, a number of specific interventions were examined, resulting an additional 24,3% of energy savings. More specific, substitution of conventional lamps resulted 8,6% savings of total consumption, corresponding to 81.000 kWh/year, reducing by almost 10.000€ (9,4%) the annual operation costs. The specific measure has great performance taking under consideration the resulting payback period of 1,8 years.

Slightly better results have the photovoltaic plant installation regarding energy savings. More specific, the 64kWp system examined, achieved a total amount of energy at 86.700 kWh (9,2%) of total savings. The corresponding operational costs savings were more than 10.500€ (10% of the total yearly costs). In this case although, the investment was significantly higher, at 74.000€, resulting a payback period of 7 years.

Due to the high percentage of glazing on the building envelope, the installation of low emissivity window films was also examined, resulting satisfactorily performance. More than 49.700 kWh/year saved (5,3% of total) along with 4.360€ of energy costs (4,1%). Some other interventions proposed as well, such as the installation of solar thermal plant and variable frequency drivers for AHU by CO_2 sensors. Additional savings of 0,4 and 0,8% of total consumption were achieved, concluded the percentage of 24,3% energy savings. 26.250€ saved through the interventions examined, connected to a total investment of 110.000€ with a payback period of 4,2 years.

The new energy consumption after interventions reduced from 143 kWh/m^2/year to 108,5 kWh/m^2/year

Table 5 Financial and energy saving results for each measure examined - Office building in Athens

ESM Recommendation	Savings [kWh/year]	% Energy Savings	Savings [€/year]	% Financial savings	Investment [€]	Simple Payback [years]
Substitution of conventional lamps	81.028	8,6	9.885	9,4%	17.405	1,8
Variable frequency drives for AHU by CO_2 sensors	7.678	0,8	937	0,9%	4.000	4,3
Improve solar factor	49.768	5,3	4.367	4,1%	9.700	2,2
Solar thermal plant	3.960	0,4	483	0,5%	4.800	9,9
Photovoltaic plant	86.717	9,2	10.579	10,0%	74.000	7,0
TOTAL	**229.151 kWh/year** **108,5 kWh/m^2**	**24,3%** of total consumption	**26.251**	**24,8%** of total yearly costs	**109.905**	**4,2**

3.3.5. Leisure and Sports centre in Chania

The three buildings complex in north Crete has been constructed separately, therefore different energy needs arise for every segment of the facility. Bowling and cinema buildings have the same common problem identified, the insufficient cover of heating and cooling needs. High temperatures are noticed indoors during summer, especially in cinema building. During winter time, heating systems are on only when the rooms are occupied, resulting an important response time for HVAC to reach at satisfactorily indoor temperature levels. In addition, the indoor spaces in both buildings ventilated insufficient, therefore, the thermal comfort conditions to characterized uncomfortable from the occupiers.

As a result, the first intervention examined was the substitution of all 4 segments of heating and cooling system and the installation of heat pumps instead, in order to cover sufficiently the needs of cinema and bowling buildings. Due to the GREPCon tool operational framework, heating and cooling needs should be taken under consideration and calculated as separated measures.

Consequently, energy savings from heating needs were about 80.000k kWh/year (9,3% of total), saving about 16.500€. The corresponding savings for cooling were 91.970 kWh/year (10,7% of total). Both interventions could achieve a total amount of more than 30.000€ of operating costs per year.

As described above, the orientation of the building and the high percentage of glazing in the south surface of the building, increasing significantly the energy needs, especially for cooling. Installation of low emissivity window films is examined for cinema and bowling buildings, presenting a great performance regarding the calculated savings. More than 73.000 kWh/year were the energy savings from this measure, corresponding to 13.000€ financial savings. The total investment of 15.000€ has a short payback period of 1,1 years.

The main entrances both of cinema and bowling buildings are permanently open, therefore, the simple installation of air curtains in both entrances was also examined. Due to the direct impact of heating and cooling consumption for the common spaces (over 1.000m^2), this measure performs impressive results, reaching total saving of 16.000kWh/year, resulting a payback period less than a year for an investment of 6.000€.

In addition to the measures described before and presented in project results, was examined the substitution of window frames and glazing. The savings achieved are 15% of total energy (almost 132 MWh) and corresponding financial savings are more than 13.000. Due to the total investment costs (121.000 €) resulted a payback period of 8,8 years, this intervention was not included in project results, but presented to the owners in order to have an overall view regarding the significant energy savings achieved through it.

Last but not least, the installation of a 50kWp photovoltaic plant was studied. The facility uses only electricity to cover its energy needs, consequently, it's proposed the maximum permissive capacity for the PV system according to national legislation limits for the non-interconnected island of Crete. About 75.000 kWh saved per year (8,7 of total), resulting a payback period of 4,3 years for the 57.500€ investment.

The total energy performance of the facility reduced from 216 kWh/m^2 to 80 kWh/m^2, by saving more than 0,5 GWh (543.300 kWh/year) for a total investment of 300.000 €, resulting a total payback of 3,1 years.

Table 6 Financial and energy saving results for each measure examined - Leisure and Sports centre in Chania

ESM Recommendation	Savings [kWh/year]	% Energy Savings	Savings [€/year]	% Financial savings	Investment [€]	Simple Payback [years]
Substitution of cooling system	91.970	10,7	16.481	10,7	50.000	3,0
Substitution of heating system	79.961	9,3	14.329	9,3	50.000	3,5
Air curtains	90.147	10,5	16.154	10,5	6.000	0,8
Improve solar factor	73.163	8,5	13.111	8,5	15.000	1,1
Substitution of windows	131.962	15	23.599	15,3	121.000	8,8
Photovoltaic plant	75.000	8,7	13.440	8,7	57.500	4,3
Occupancy and presence sensors	343	0,04	61	0,1	540	8,8
TOTAL	**542.300 kWh/year** **80 kWh/m^2**	**62,7%** of total consumption	**97.175** €/year	**62,9%** of total yearly costs	**300.028 €**	**3,1**

3.3.6. Hospital in Athens

The last case, the maternity and pediatric clinic was also a challenge due to the intensive energy needs (24/7 hospital) and the total size of the facility. The 45.000m^2 buildings complex has a total consumption of 19 GWh – 456kWh/m^2 per year, but the challenge here was the further energy savings achieved. In the facility, a number of interventions have already implemented, achieving important amount of energy such as substitution of windows, Building Energy Management System for efficient control of overall energy demands, substitution of conventional lamps with LED lamps, shading devices for windows in both buildings, 5 cm EPS insulation on the building envelope etc.

Consequently, interventions in order to manage more efficiently the energy needs, were proposed such as the substitution of a conventional boiler with a condensing boiler for DHW needs. An amount of almost 475 MWh/annually is saved from this measure, corresponding to 2,5% of total consumption. Financial savings are over 19.500€ per year, resulting a payback period of 7,2 years for the 140.000€ investment.

The installation of low emissivity window films was examined also in this case, resulting a reduction of 3,1% of total consumption, calculated about 600 MWh/year. The installation of a heat recovery system combining with the boiler in order to take advantage of wasteful energy released to the atmosphere. Heat recovery systems could achieve 233 MWh energy savings annually, reducing the operational costs by almost 10.000€.

At last, the installation of 191 kW PV plant was examined through the construction of a car-sharing system for the outdoor available parking area. The PV plant has 296.000 kWh yearly production, 1,2% of total energy consumption. The total investment of 324.800€ has a payback period of 8,6 years.

Table 7 Financial and energy saving results for each measure examined - Hospital in Athens

ESM Recommendation	Savings [kWh/year]	% Energy Savings	Savings [€/year]	% Financial savings	Investment [€]	Simple Payback [years]
Substitution of conventional boiler with condensing boiler	474,630	2,5	19,507	1,2	140,000	7,2
Improve solar factor	598,432	3,1	24,596	1,5	60,000	2,4
Heat recovery systems	233,179	1,2	9,584	0,6	75,000	7,8
Photovoltaic plant	296.000	1,5	37,562	2,3	324,800	8,6
TOTAL	**1,602,241 kWh/year** **395,8 kWh/m^2**	(8,3% of total consumption)	**91,249**	**5,5%** of total yearly costs	**599,800**	**6,6**

As a conclusion, the measures proposed and studied for the case of the hospital have not an impressive performance compare to the other 3 pilot cases, the total reduction reaches only the 8,3%. But those measures could achieve an amount of energy over than 1,6 GWh per year, corresponding to 91.250€, through an investment of about 600.000€. The overall energy performance of the hospital after the interventions is 396 kWh/m^2/year.

Chapter 4
Discussion

Tertiary sector buildings in Greece presenting an increased potential for decarbonization of the sector, due to the high amounts of energy could be saved through a list of interventions. Most of them are old, low energy efficiency performance buildings, providing a challenge for the Member States to manage. The results recorded are going to further analysed in terms of energy savings, financial and environmental benchmarking. On table 7 are presented the total of interventions results, along with the technical – economical and sustainability indexes.

Table 8 Results from passive, active and Renewable Energy systems for energy saving, sustainability and economical indexes for all 4 cases

Buildings				
Sector	**Resort & SPA Hotel**	**Office**	**Hospital**	**Leisure and Sports Centre**
Descripiton	18.018 m2 Resort in Sisi, Lasithi, 15 buildngs complex, SPA, 1 indroor, 5 oudoors, 21 private swimming pools, May - Octomber	6.575 m2 Office building in Ahens, 2008 structure, bioclimatic architecture, ISO 50001:2011, 7 floors, 1 basement, 5 level underground parking	A 45,000 m2 hospital 2 underground-connected buildings complex, main constructed in 1994, new added in 2004 (child sector)	4.172 m2 Leisure and soprts centre in Chania, structure of 2003, non - urban area 3 buildings complex; bowling, cinema, pastry Daily operation, annually
Type of Energy	Electricity (H) Biomass (DHW) Fuel (DHW) Solar thermal (DHW)	Natural gas (H) Electricity (C)	Electricity Natural Gas (H&C)	Electricity (H&C)
Total Energy consumption (kWh/yr)	**2.082.017**	**942.554**	**9.443.389** **11.075.640**	**862.200**
Total Energy consumption (primary, kWh/yr)	3.803.147 284.334 536.719 **4.624.200**	177.563 2.292.035 **2.469.599**	27.385.828 11.629.422 **39.015.250**	**2.500.380**
Actual Energy consumption (kWh/m2/yr)	**115,6**	**143**	431,4	**207**
CO2 emissions ($kgCO_2eq/m2/yr$)	77	123	340	204

Energy Savings Scenarios					
Passive interventions (kWh/year & savings percentage)	**Thermal insulation of building envelope**	**47.507** 3%	Already implemented	Already implemented	Not implemented, limited available free space
	Substitution of windows	**47.508** 3%	Already implemented	Already implemented	**131.962** 15%
	Substitution of doors (automatic door)	Not implemented	Not implemented	Already implemented	90.147 10%
	Improve solar factor	**45.507*** 3%	**49.768** 5,3%	**598.432** 3%	73.163 8%
	Installation of ceiling fans	Not implemented	Not implemented	Not implemented	Not implemented
Active systems (kWh/year & savings percentage)	**Substitution of conventional lamps**	**42.324** 2,6%	**81.028** 9%	Already implemented	Already implemented
	Sensors (occupancy & presence)	Not implemented	**7.678** 1%	Not implemented	**343** 0,04%
	Substitution of appliances - laundry	Not implemented	**-**	-	-
	Substitution of appliances - kitchen	Not implemented	**-**	-	-
	Substitution of low efficiency chiller	**390.073** 24,5%	Not implemented	-	91970 11%
	Substitution of boiler burner		Not implemented	**474.630** 2%	79961 9%
	Heat recovery systems	**294.540** 14,1%	Not implemented	**233.179** 1%	Not implemented
Renewables (kWh/year & savings)	**Solar thermal plant**	**152.413** 10%	Not implemented	Not implemented	Not implemented
	Photovoltaic plant	**75.000** 4%	**86.717** 9,2%	**296000** 2%	75000 9%

Technical - Economical	**Investment cost €/kWh saved for the system physical lifetime** *Investment cost Annual savings in kWh*	**Substitution of conv lamps with LED ***	**Substitution of conv lamps with LED**	**Improve solar factor**	**Substitution of windows**
		0,09	0,05	0,01	0,04
		Heat pumps installation	**Improve solar factor**	**Substitution of boiler**	**Substitution of doors**
		0,03	0,01	0,01	0,01
		Substitution of windows	**Solar thermal plant**	**Heat recovery systems**	**Improve solar factor**
		0,03	0,04	0,02	0,01
		Thermal insulation of building envelope	**PV plant**	**PV plant**	**Substitution of boiler burner**
		0,05	0,04	0,01	0,03
		Heat recovery systems			**Substitution of chiller**
		0,01			0,03
		Swimming pool heat cover			**Occupancy and presence sensors**
		0,04			0,13
		Solar thermal plant			**PV plant**
		0,02			0,04
		PV plant			
		0,04			
		*3111 units	*3027 units		
Sustainability Indexes	**Investment cost /kg CO2eq saved** *Investment cost Annual kg CO2 savings*	**Substitution of conv lamps with LED ***	**Substitution of conv lamps with LED**	**Improve solar factor**	**Substitution of windows**
		0,13	0,06	0,04	0,05
		Heat pumps installation	**Improve solar factor**	**Substitution of boiler**	**Substitution of doors**
		0,03	0,02	0,08	0,01
		Substitution of windows	**Solar thermal plant**	**Heat recovery systems**	**Improve solar factor**
		0,03	0,04	0,08	0,01
		Thermal insulation of building envelope	**PV plant**	**PV plant**	**Substitution of boiler burner**
		0,05	0,04	0,06	0,03
		Heat recovery systems			**Substitution of chiller**
		0,00			0,03
		Swimming pool heat cover			**Occupancy and presence sensors**
		0,14			0,13
		Solar thermal plant			**PV plant**
		0,00			0,04
		PV plant			
		0,04			
		*3111 units	*3027 units		

In order to calculate the investment costs for technical systems, the physical lifetime of the selected systems was need to be determined (table 9), along with emission factors per form of energy according to national directives (table 10).

It should be also mentioned that GREPCon tool is taking under consideration the emissions factor as defined in national level for each country but there is direct connection to energy mix percentages of each country.

Therefore, for electricity source of energy, was taken under consideration the percentage of renewables at electricity grid which reaches the 27% for Crete (non-interconnected island grid) and 18% for Athens (mainland interconnected electricity grid).

Physical Lifetime of Systems - years		
LED Lamps	Heat pumps - Heat recovery	**Calculation Formula = investment cost/(annual energy savings * system lifetime)**
40.000 hours 5 years	20	
	Substitution of door	
Thermal insulation	10	
30	Solar thermal plant	
PV plant	30	
20	Solar factor, low-e films	
Windows	15	
25	Boiler burner	
Swim heat cover	20	
10	Chiller	
Window films	20	
15	***Source: National Legislation, Law 4172/2013, Article 24 Regarding Depreciation Period*** ***[28]***	
Sub of appliances (aver)		
10		
Occupancy sensors		
12		

Table 9 Physical lifetime of systems

CO_2 emissions factor*		Penetration of RES in **electricity** grid
Electricity	0,989	Crete : 27%
Gas	0,196	Athens : 18%
Fuel	0,264	
DH	0	
**GR factors for TRUST EPC – 2004/156/EC*		

Table 10 CO_2 emissions factor for the energy sources

On the charts presented below are depicted the corresponding energy savings achieved per measure, for each different type of building, in order to present an overall view for measures examined and their efficiency.

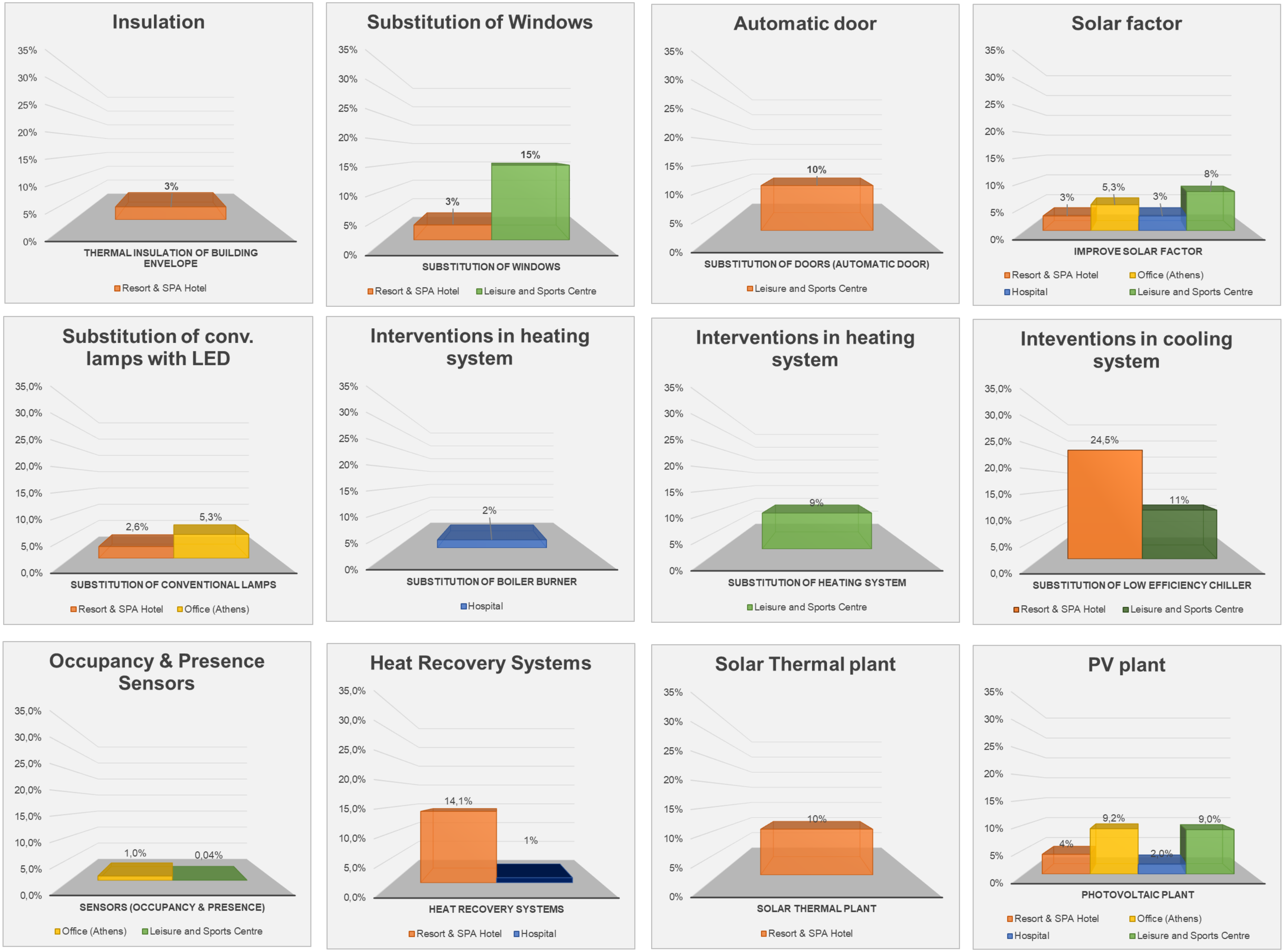


Figure 17 Benchmarking of examined measures implemented for the selected type of buildings

As expected, every energy savings measure has its own impact on the building were implemented. Through the charts presented below, are depicted the variations noticed by investigating the same measure on a different type of buildings, along with the efficiency of every measure compare to another one. For instance, thermal insulation of building envelope resulted savings at 3% of the total for Resort & Spa Hotel. It should be noticed though, the fact of seasonality operation of the accommodation which reduces more than the half the potential energy savings. Furthermore, the measure of installing insulation was evaluated for specific segments of the building complex, not for the overall envelope of the building. Generally, thermal insulation does not present the most satisfactory results, but constitutes an important intervention especially for accommodation building in order to improve the indoor air quality and thermal comfort conditions.

On the other hand, substitution of windows is presenting a great performance in terms of energy saving reaching for leisure and sports centre in Chania. The corresponding savings for Resort Hotel are only 3% of the total, but this is due to the implementation of the measure at only one specific building of the 15 buildings of the facility, where identified low performance due to the old window frames and the high percentage of glazing on the building façade. Considering though the amount of energy saved individually for that specific building, the savings are significantly high.

Regarding the main entrances in Leisure Centre, was examined the substitution of permanently open glass doors with automatic doors. The measure resulted satisfactorily results reaching 10% of the total consumed energy annually.

An interesting comparison is the installation of low emissivity window films in order to improve the solar factor of glazing, due to the measure was applied in several pilot cases. More specific, a

3% of energy savings achieved for Resort Hotel, 5,3% for office in Athens, 3% for Hospital and 8% for leisure centre. The values detected are not very high a percentage of total consumption, representing though important amounts of energy. The 3% of Hospital in Athens corresponds to about 600 MWh per year and the 5,3% for Office building in Athens are 50 MWh annually savings.

Substitution of conventional lamps with LED lamps was the most common energy saving intervention investigated throughout the project and this Thesis study implementation. It was examined for Resort and Spa hotel resulting 2,6% and at Office building in Athens, resulting 5,3%. Regarding the hotel, it should be mentioned that the replacement concerns only the lamps in common spaces such as halls, corridors and common WCs. Within the guest rooms, the lamps had already been replaced. This measure performances significant savings especially in office buildings were the lighting has an important role in order to achieve comfort conditions.

Substitution of heating and cooling systems were examined in specific cases, where needed, after discussions with owners and evaluation of their preferences, according to methodology followed. More specific, regarding the hotel, only cooling loads were taken under consideration and calculated, due to seasonality operation. The cooling system was replaced by heat pumps (within the tool, the measure called "substitution of low-efficiency chiller" in order to cover more cases), achieving 24,5% savings, corresponding to 390 MWh per year. In the case of Leisure Centre were examined interventions in HVAC system also, resulting 11% savings of total energy consumption, corresponding to almost 92 MWh. Heating system substitution was examined also in leisure centre, resulting satisfactorily savings at 9% of total (about 80 MWh). Regarding the hospital, substitution of boiler burner was connected with DWH consumption, not the heating system using natural gas. The 2% savings although, corresponds to almost 0,5 GWh (474MHh), characterizing the measure as an efficient one.

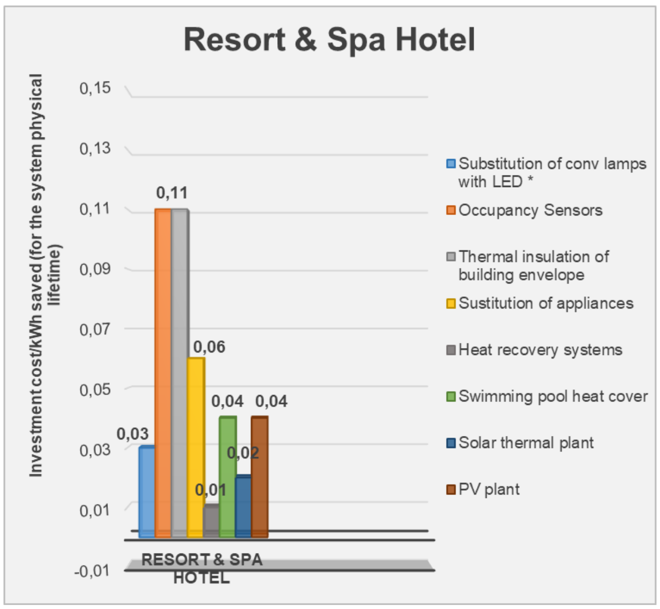
In general, upgrading of heating and cooling systems recommends a high-efficiency measure, as resulted from investigated cases and arise from literature for decades. Nevertheless, the high costs of investments required for the tertiary sector buildings, as will present within the next charts, leads to investigate other alternative interventions.

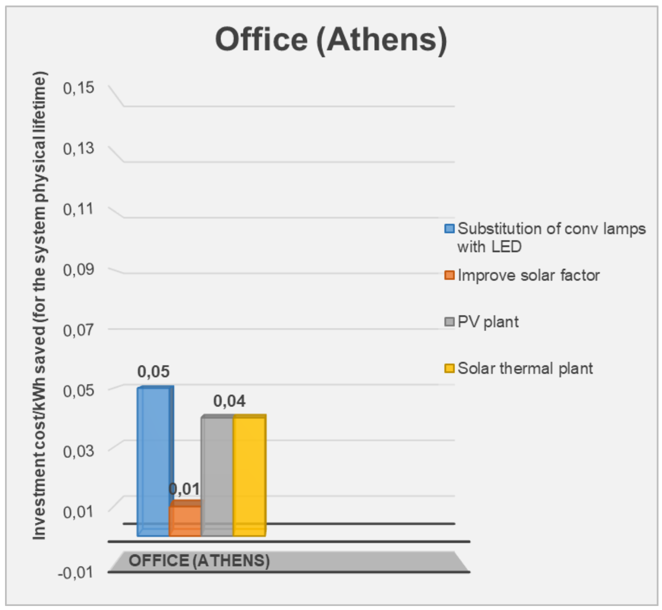
Occupancy and presence sensors installation was examined in various types of buildings, concluding an average 0,5% of savings on an annual base. Regarding this measure, the recorded savings may be low in a matter of the amount of energy for tertiary sector buildings, but representing the simplest intelligent-control system intervention for lighting in buildings and along with substitution of conventional lamps, could reach the target for a near zero building.

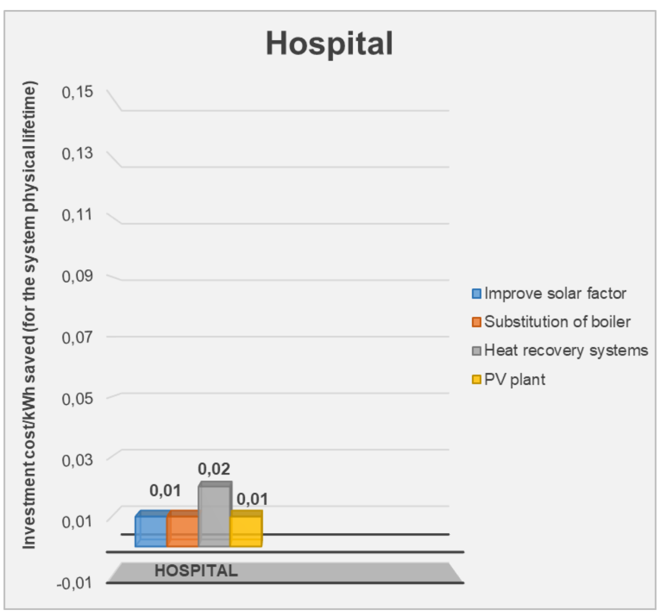
Finally, the solar energy systems were investigated in order to reduce electricity and DHW needs. More specific, solar thermal plants were evaluated as an energy savings measure for the hotel where a high amount of energy for DHW required. The amount of energy savings achieved was significant at the case of Resort & Spa Hotel, reaching 10% of total energy (more than 152 MWh). Currently, the hotel covers its needs for DHW by oil burners.

Photovoltaic plants installation was evaluated as a measure for the total of investigated buildings, hotel, office building, hospital and Leisure centre. Interesting results are presented here, such as the 4% savings of resort and spa hotel, by examining the maximum capacity permitted system of 50 kWp due to legislation limits. The explanation of low performance includes the energy source. The resort and spa hotel uses electricity, biomass, oil and solar energy as well. Therefore, corresponding savings are not significantly high, comparing to a whole electricity facility, such as a leisure centre. In that case, the results were more satisfactorily reaching 9% of the total. Installation of an embedded PV plant on shading structure for parking could reduce electricity needs for the hotel up to 296 MWh (2%). Concluding, exploitation of solar energy included within the necessary steps in order to achieved near zero energy goals for the tertiary buildings as well.

In order to have an integrated view regarding the efficiency of each measure for the various types of buildings, financial and environmental indexes were calculated (table 7), and presented on the following charts.







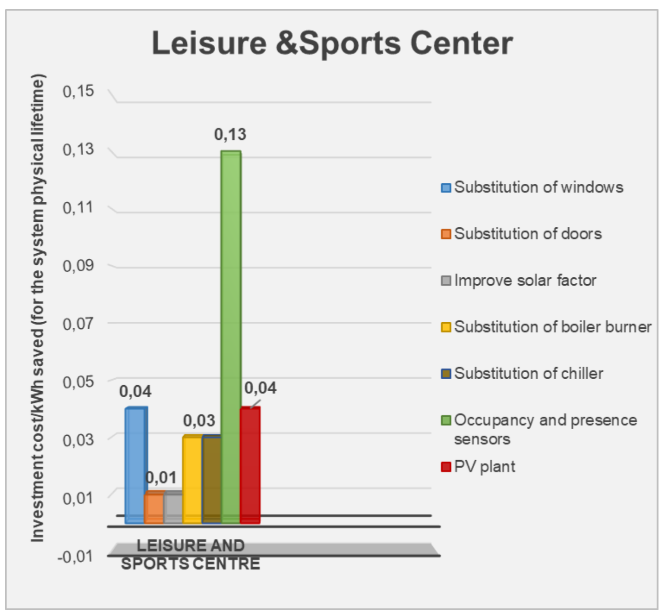


Figure 18 Financial indexes of examined measures per type of building

The investment cost per kWh saved is presented on the charts, taking under consideration the physical lifetime of each system proposed (table 9).

The values presented could easily evaluate each measure regarding its financial efficiency. For instance, substitution of conventional lamps with LED lamps, resulting 0,03€/kWh saved for the hotel and 0,05€/kWh for the office building, depicting the high efficiency of this intervention in the terms of energy and corresponding investment required, even their short physical lifetime (5 years) compare to other systems averages (more than 10 years).

Among the measures recorded, satisfactorily results are the installation of low emissivity window films in order to improve solar factor, which presents values at 0,01 €/kWh for office buildings, hospital and leisure centre, as well.

Heat recovery systems performed also interesting results, reaching at 0,02€/kWh for Resort & Spa hotel and hospital. Generally, heat recovery systems could provide great results for high energy consumption buildings like those of the tertiary sector.

Significant higher cost per kWh saved resulted the occupancy and presence sensors compare to other measures, wherever proposed, resulting 0,13 €/kWh for leisure centre and 0,11€/kWh for a hotel in Rethymno.

In order to calculate the corresponding environmental index, the energy source of each measure should be taken into consideration, in order to convert the energy savings to the amount of CO_2 emissions saved. The conversion factors as they have been proposed from national legislation through the updated “Technical Guidelines” for the Energy Efficiency of Buildings in Greece, arise from the revised EPBD (table 10).

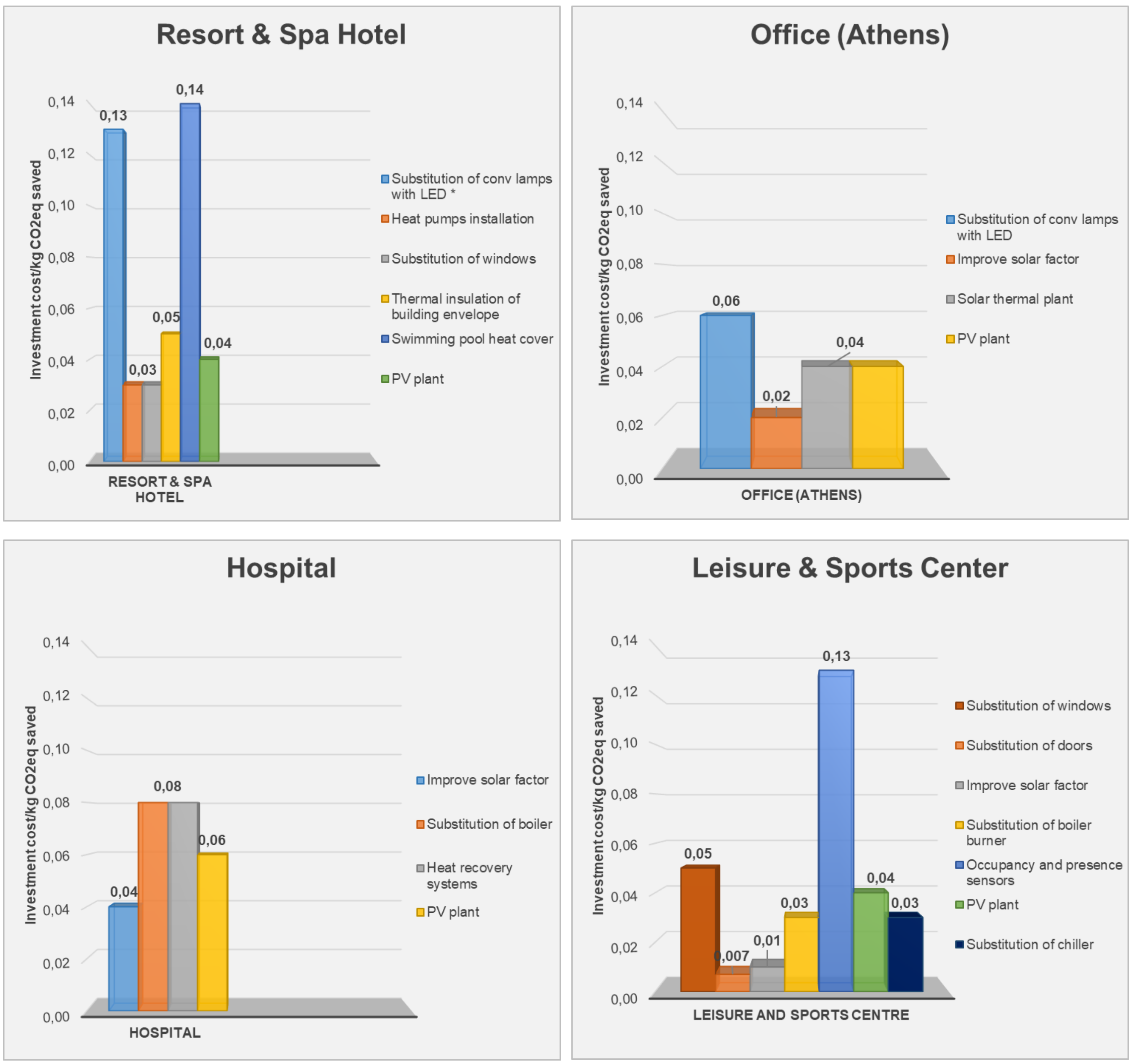


Figure 19 Environmental indexes of examined measures per type of building

The evaluation here aims to highlight the measure could achieve the higher "decarbonization" of the buildings by reducing the CO_2 emissions from the kWh saved and purchasing the less amount of money.

Installation of photovoltaics performed as expected satisfactorily results, from 0,04€/kgCO_2eq for Resort & Spa hotel, Offices in Athens and Leisure centre and 0,06€/ kgCO_2eq for Hospital.

Heat pumps and substitution of windows are also presented high performance, at 0,03€/ kgCO_2eq for the case of a hotel. Similar satisfactory performance achieved the measure for leisure centre at 0,04€/ kgCO_2eq but quite difference noticed for the case of the hospital, recorded 0,08€/ kgCO_2eq saved.

Impressive results show the installation of low emissivity window films (0,01€/ kgCO_2eq and installation of air curtain (0,007€/ kgCO_2eq), representing the high amount of energy saved from those measures for all types of buildings examined.

Following the financial indexes, occupancy and presence sensors included among the less cost/environmental efficient measures, requiring 0,13€/ kgCO_2eq for the leisure centre.

Substitution of lamps with LED presented also a not satisfactorily result at 0,13€/ kgCO_2eq, mainly due to the high penetration of RES in electricity grid of Crete, the initial investment cost and corresponding savings. The difference compare to office buildings in a different region is obvious: the same measure for the office building in Athens resulted 0,06€/ kgCO_2eq. This measure recorded as a highly recommended from EU both in residential and tertiary sector buildings, nevertheless, in terms of environmental efficiency, due to the short physical lifetime has not the same performance.

There are some quite efficient interventions such as thermal pool cover for the indoor heated pool of Spa hotel and the heat recovery systems in the hospital, which presenting disappointing results in the matter of cost pre $kgCO_2$ saved. That fact could be easily explained by the energy source connected to those measures which are biomass and natural gas, respectively. As shown in table 10, their conversion factors are zero for biomass and 0,196 for natural gas, therefore, their overall performance is not efficient regarding CO_2 emissions associated.

Generally, the most satisfactory performance regarding the environmental indexes present the measures connected with electricity such as lighting, PV plants or interventions in HVAC systems consuming electricity.

Chapter 5
Conclusion and recommendations for the future

The buildings of the tertiary sector within the Member states of EU, shown a great potential for energy saving renovations. The age of the buildings, the barriers in financing, the lack of trust between stakeholders, have led to minimum renovations of old tertiary sector buildings in Greece.

In this master Thesis, 4 types of buildings were investigated through a robust methodology including a standardization tool, in terms of benchmarking the energy efficiency, cost efficiency and sustainability for each measure examined.

The selection of buildings was based on the extended market analysis both in European and national level, the applicability level of each type of building in Greece and their ranking in higher energy consumers per floor area list.

The results recorder has led to the following conclusions for each building case:

- **The Resort and Spa Hotel** achieved a total of 55,8% of its total consumption by implementing the eight energy savings measures proposed, reducing its annual consumption from 115,6 kWh/m^2/year to 55,8 kWh/m^2/year.

  The total investment was 596.500€ resulting a payback period of 5,2 years.

  Regarding the energy efficiency indexes, the more efficient measures examined recorded the substitution of the cooling system with 24,5% and the heat recovery systems installation with 14,1%.

  Financial indexes highlighted for the hotel the heat recovery systems as more efficient resulting investment cost 0,01€/kWh saved (for the system physical lifetime), following by solar thermal plant (0,02€/kWh saved) and substitution of conventional lamps with LED (0,03€/kWh saved).

Simultaneously, environmental indexes for each measure calculated taking under consideration the energy savings and the corresponding energy source along with the investment cost, resulting the heat pumps and the substitution of windows as the most efficient measures in terms of investment cost per kgCO_2eq saved. Both of them resulting 0,03 €/kgCO_2eq saved, followed by PV plant with 0,04€/kgCO_2eq saved.

- **In the Office building in Athens**, a total reduction of 52% of energy consumption was calculated by implementing the five measures proposed. The annual energy consumption for the facility was reduced from 143 kWh/m^2/year to 108,5 kWh/m^2/year.

  The total investment was about 110.000€ giving a payback period of 4,2 years.

  In the case of office, the measure recorded the higher energy savings was the photovoltaic plant (9,2% savings of total energy consumed) followed by substitution of conventional lamps with LED lamps (5,3% of total energy).

  Financial indexes shown as the most efficient in terms of investment cost per kWh saved, the solar factor improvement by installing low emissivity window films (0,01€/kWh saved) followed by PV plant and solar thermal plant installation (0,04€/kWh saved).

  Furthermore, the environmental indexes showed off the solar factor improving as the most sustainable measure in terms of cost per CO_2 emissions, resulting 0,02€/kgCO_2eq saved while the corresponding value of PV and the solar thermal plant was 0,04€/kgCO_2eq saved.

- **Leisure and Sports centre in Chania** was the case with the most satisfactory results, mainly due to low-quality materials of bowing building envelope and the absence of automatisms and control systems during the off hours.

  More specific, the examined measures recorded 62,7% of total consumed energy (about 542.300 kWh/year). Its annual consumption reduced from 216 kWh/m^2 to 80 kWh/m^2.

  The total investment was 300.000€ with a payback of 3,1 years.

  The more energy efficient measures were the substitution of windows resulting 15% savings of total consumption, along with interventions in cooling (11%) and heating system (9%). The same results gave also the solar factor improving (9%).

  Taking under consideration the investment cost in parallel, installation of air curtain and solar factor improving detected the lowest values for investment cost per kWh/saved, resulting at 0,01€/kWh saved. Up next was the interventions in heating and cooling systems (0,03€/kWh).

  Regarding the emissions associated with each measure, installation of air curtains resulted 0,007€/kgCO_2eq saved. Solar factor improvement and interventions in heating and cooling system were also recorded low value at 0,01 and 0,03€/kgCO_2eq saved, respectively.

- Concluding**, the Maternity and Pediatric Clinic in Athens**, a big size hotel with high energy consumption on annual base, resulted a total of 8,3% savings, corresponding to

1,6 GWh per year. The initial energy performance of the hospital was 456 kWh/m^2/year, while after interventions reduced at 396 kWh/m^2/year.

The total investment reaches the 600.000€ with a payback of 6,6 years.

The investigated measures for the hospital highlighted as the more efficient measure in terms of amount of energy saved, the installation of low emissivity films, reaching at 3,1% which corresponds to 600 MWh/year, followed by the substitution of conventional boiler with condensing (480 MWh savings per year - 2,5% of total energy).

Financial indexes shown the substitution of the boiler, installation of low emissivity window films and PV plant installation as the more efficient measures, resulting investment cost 0,01€/kWh saved. Heat recovery systems are following with 0,02€/kWh saved.

Lastly, environmental indexes for each measure proposed, resulted the same almost the ranking as the financial ones. More specific, 0,04€/kgCO_2eq saved shown the installation of low emissivity window films, followed by the PV plant recorded 0,06€/kgCO_2eq.

This Thesis has main aim the benchmarking through a standardization tool in order to present an integrated assessment of energy saving potential in a variety of tertiary sector buildings, including also financial and environmental schemes. In order to exploited more enhanced results, an extended and integrated analysis included additional buildings in terms of energy efficiency per type of building could be implemented.

Further research in the future could furthermore include the study of all types of buildings in the tertiary sector, such as educational buildings, universities and schools, libraries, services, shopping centres, logistics. Special interest could have the results of the same measures implemented and evaluated for the total of buildings investigated, including additional measures were not available in this Thesis, besides the 47 provided by the GREPCon tool, such as ceiling fans installation (high efficient measure especially in accommodation buildings in South Europe) and specific smart systems for total building control and monitoring. Within this framework, an energy, financial and sustainability guide could be developed, as an integrated representative of energy saving measures for tertiary sector buildings.

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