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Exploitation of Mediterranean Cooperation Projects' Tools for the Development of Public Buildings' Energy Efficiency Plans at Local Level: A Case Study in Greece

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Abstract: Ever since European Directive 2012/27/EU, particular attention has been focused on the improvement of the energy efficiency of the public building stock. According to the directive, local public authorities, regions and municipalities, are expected to develop and implement energy efficiency retrofitting plans for their public building stocks. While conducting such plans, important challenges are raised mainly related to data collection and the manipulation of key performance indicators (KPIs) for many buildings. The present paper deals with the aforementioned challenges through (a) the evaluation of freely available tools developed in the framework of Mediterranean territorial cooperation projects, with respect to the main pillars of energy efficiency planning, and (b) the introduction of a stepwise methodology using selected tools toward a reliable energy efficiency plan extending from the classification of the building stock to the prioritization of projects in terms of a gradual renovation plan based on energy and cost criteria. The methodology is applied for a case study in Greece, which refers to 10 public buildings of the Municipality of Aigialeia in Greece. A reliable renovation plan is developed, taking into account the municipal authority's directions in a specialized decision-making scheme. It is concluded that the suggested methodology is very practical for planning purposes, while for the case studied, a 6-year gradual renovation plan is emerged until a deep retrofit of all buildings, associated with an estimated primary energy saving and CO_2 emissions avoidance of more than 1850 MWh and 400 tns, respectively, with a total investment of about EUR 3 million.

Keywords: public buildings' energy efficiency plans; local public authorities; public building stock; buildings' typologies; building renovation planning

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Citation: Stavrakakis, G.M.; Zervas, P.L.; Terzis, K.; Langouranis, P.; Saranti, P.; Stephanedes, Y.J. Exploitation of Mediterranean Cooperation Projects' Tools for the Development of Public Buildings' Energy Efficiency Plans at Local Level: A Case Study in Greece. *Energies* **2023**, *16*, 3352. https://doi.org/10.3390/en16083352

Academic Editor: Jurgita Raudeliūnienė

Received: 8 March 2023
Revised: 2 April 2023
Accepted: 4 April 2023
Published: 10 April 2023

1. Introduction

The building sector in the European Union (EU) stands for the largest energy consumer with around a 40% share of the final energy consumption [1]. According to the European Commission's records, almost 50% of the EU's final energy consumption is attributed to heating and cooling, of which 80% is allocated to buildings [2]. These figures advocate the urgency of increasing the renovation rates of the building stock in view of achieving the ambitious targets of the EU Green Deal (EGD), which sets a minimum of 55% greenhouse gas emissions reduction by the year 2030 in the EU [3]. Specifically for the building sector, the commission has introduced the exemplary role of public buildings for over a decade with energy efficiency directive 2012/27/EU [4] and more recently with its recast 2018/2002/EU [5]. According to these directives, the public sector should lead by example in planning and implementing building renovation projects, and member states shall encourage regions and municipalities to adopt an energy efficiency plan containing specific energy saving and efficiency objectives and actions. In compliance with recent policy recommendations [6], member states are establishing long-term renovation strategies focused on both public and private buildings, toward a highly energy efficient and decarbonized building stock by 2050, also including measures for the cost-effective transformation of existing buildings into nearly zero-energy buildings (the so-called nZEBs).

Despite the rather mature EU policy framework, it has been reported that the European building sector, so far, presents an insufficient renovation rate, it being as low as 1% of the existing building stock [7], which diverges significantly in achieving even the short-term goals for 2030. Among the various technical, financial and social reasons hindering building renovation, the lack of technical expertise and planning skills, as well as the complex decision-making processes, have been acknowledged [8,9]. Such barriers are escalated at the local level, i.e., regions and municipalities, because of the requirement for managing diverse building types and deciding among a plethora of alternative pathways regarding public building stock renovation projects. It has been further suggested that in meeting the ongoing buildings' energy efficiency policies, informed decision making is a prerequisite and, in fact, is based on reliable quantification of state and impact KPIs for the various renovation scenarios [10]. The latter study reviews numerous available computational tools that are freely commercially available for building energy performance quantification purposes, accompanied with a vast amount of worldwide case study applications using these tools; however, it is restricted to single-building processing rather than to a group of buildings, which is the main focus in the case of building-stock energy planning. To face the challenge of manipulating numerous buildings in view of planning energy renovation, Napoli et al. [11] introduced a participatory multi-criteria decision aid model, involving an experts' panel in the decision-making scheme structuring, toward sorting alternative energy retrofitting actions into various categories and eventually prioritize the scenarios based on financial and technical criteria. The approach successfully adopted the typology approach, based on which the buildings and measures were grouped into typologies to accelerate calculations for large building stocks. The methodology was applied to a sample of 36 public buildings in southern Italy and led to a reliable hierarchy of 210 energy retrofit interventions.

The typology approach for building-stock energy planning has been widely used in the past decade. It consists of the classification of the building stock into representative groups of buildings based on the characteristics with major influence on energy performance (e.g., building use, age, number of floors, heating/cooling system, etc.). Adopting the construction period, the building size and the climate zone, suitable efficiency measures for the national residential building stock has been demonstrated in ref. [12]. Provided that the classification of buildings into representative typologies is technically valid (i.e., the correct classification criteria that principally influence the energy performance and their ranges are adopted), the main advantage of the approach is that it provides the (nearly) instant projection of state and impact KPIs from a single representative building to the rest of the same typology, therefore accelerating the production of the KPIs' database for the whole building stock initially considered, which can be further used to plan renovation projects and investments. Application examples may be found in numerous studies EU-wide [13–17]. On a large scale, the approach has been successfully tested in the framework of the TABULA project [18] in 13 EU countries, providing energy efficiency solutions for residential houses. More recently, Herrando et al. [19] applied a typology-based approach for the development of an energy renovation plan for public buildings at the local level in the case of Teruel province in Spain. It was suggested that the proposed approach was very useful, especially for small local authorities with limited expertise in energy efficiency planning. However, since only the building use was adopted as a classification criterion, energy performance indicators, at least in the existing situation, were absolutely necessary inputs for all buildings of the stock to develop a realistic plan. A good example of overcoming the aforementioned barrier is presented in ref. [20], wherein the typology approach was employed adopting additional building parameters as classification criteria, i.e., building geometry, age, floor area, no. of floors, envelope construction materials and the heating system, toward the conclusion of representative school building typologies in Valencia and, furthermore, the identification of cost-optimal energy-upgrading measures of the thermal envelopes of the identified building typologies.

Focusing on the decision-making level of planning practices, Salvia et al. [9] presented the PrioritEE toolbox standing as a decision support tool for public buildings' energy efficiency planning in terms of ranking energy efficiency and renewable energy (EE/RES) interventions for public building stocks. Results from applying the toolbox in five Mediterranean countries, in the framework of the PrioritEE Interreg MED project [21], were presented. The interpretation of KPI-based planning using the toolbox by means of CO_2 emissions avoidance was demonstrated in ref. [22] through the case study for the Potenza Municipality. The planning exhibition revealed that the deep renovation including both RES/EE interventions for the buildings considered may lead to CO_2 avoidance of approx. 644 tns/y. Complementary to the above studies and, in fact, following the success story of the typology approach mentioned earlier, novel tools are presented in the framework of the IMPULSE Interreg MED project [23]. A brief overview of the IMPULSE tools may be found in ref. [24], presenting a tool guiding through the clustering process of the building stock toward the representative building typologies, a KPI processing tool that produces a KPI database for the building stock, and a PLUGIN embedding a multi-criteria assessment algorithm toward a gradual energy renovation road map. Extensive applications of the IMPULSE tools may be found for five municipalities in five Mediterranean countries, in the project deliverables database webpage [25]. Although recent research on the topic addressed herein provides advanced tools and methods, such as those reviewed in refs. [9,10], most of them are very advanced and require a high level of expertise, making them unattractive for practical applications on the side of the planners and decision makers of local authorities. On the other hand, it has been admitted that in operational terms, simplified EE planning tools are needed that can ideally be easily used based on already available energy performance indicators, e.g., retrieved by energy performance certificates (EPCs) [9]. The previously mentioned studies and projects originate in the "Efficient Buildings" thematic community of projects implemented in the framework of the (former) Interreg MED 2014–2020 program. Containing more than 10 projects bringing together the EU Mediterranean countries and focusing on public buildings' energy efficiency, the Interreg MED Efficient Buildings Community is perhaps the dominant expressor of the Mediterranean renovation wave. In this endeavor, public authorities, regions, municipalities and research institutes work together toward the development of common frameworks, tools and methods to accelerate public buildings' renovation rates, especially at the local level. The community tools most suited for energy efficiency planning are identified in the framework of the SEACAP 4 SDG project [26].

As far as the Greek context is concerned, according to L.4843/2021, which transposes the energy efficiency directive recast 2018/2002/EU, regions and municipalities are obliged to develop, implement and monitor energy renovation plans (ERB plans) for their public building stocks (Greek abbreviation for ERB in Latin characters: SEAK). In this framework, the Hellenic Ministry of the Environment and Energy (MINENV) has released a specific template/guide according to which these regional and municipal plans shall be conducted [27].

The present paper intends to facilitate regional and municipal public authorities in developing reliable public building energy efficiency plans through the following activities: (a) assessment of the Interreg MED's Efficient Buildings Community tools most suited for energy efficiency planning purposes with respect to the main pillars of building renovation plans; (b) presentation of a stepwise methodology exploiting selected tools for the development of building energy renovation plans; (c) demonstration of the suggested methodology for a case study in Greece.

2. Materials and Methods

This section is initially focused on the assessment of tools most suited for energy efficiency plans at the local level, specifically for Mediterranean local authorities, notably the Interreg MED's Efficient Buildings Community tools identified in the framework of the SEACAP 4 SDG project [26]. A qualitative evaluation of the tools is performed with respect to the pillars of energy efficiency planning. Thereinafter, selected tools are presented by means of a stepwise methodology tackling building-stock manipulation, grouping into typologies, and the KPIs' processing toward prioritization of renovation projects and the development of a gradual renovation plan. The methodology is demonstrated for a priority building sample of the Municipality of Aigialeia in Greece.

2.1. Assessment of Planning Tools for Public Buildings' Energy Efficiency

As mentioned previously, the tools produced in the framework of the Interreg MED's Efficient Buildings Community most suited for the energy efficiency planning of public buildings at the local level are recognized in the SEACAP 4 SDG capitalization project. In ref. [26], the project developed a toolkit that gathers the tools and reports their main scope and capabilities mainly in terms of their type (tool, method, factsheet, etc.), level of replicability, target groups and available language versions. To complement the aforementioned recording, this paper proceeds a step farther by evaluating the selected tools from the point of view of meeting the main pillars of energy efficiency planning. Based on the goals set by the relevant EU policies [6,7], as well as on the challenges identified for example in ref. [28] regarding buildings' renovation planning at the local level, the following planning pillars are recognized:

- P1: collection and organization of building-stock data;
- P2: impact assessment of the base-case situation and retrofit scenarios;
- P3: identification of suitable renovation solutions;
- P4: techno-economic parametric assessment of renovation scenarios;
- P5: prioritization of buildings and of renovation projects;
- P6: production of a gradual energy renovation plan.

Evaluation of the recognized tools in terms of addressing the above pillars is presented in Table 1. It may be concluded that:

- Most tools are not suitable for impact assessment for the various building states (i.e., base-case and retrofit scenarios), i.e., they presume externally available state KPIs obtained, for example, from available studies or EPCs, building energy simulations or measurements. Only the PrioritEE tool incorporates some averaged energy consumption values derived from national EPCs, standards and reports, at least from the partner countries, to confront the challenge of absent base-case state KPIs.
- All tools are freely available for instant use in a web environment or instant download, except for the PrioritEE tool and the EDUFOOTPRINT calculator, which require some administrative processing to obtain access.
- The majority of the acknowledged planning pillars, specifically focused on public buildings' energy renovation, is addressed by the PrioritEE and the IMPULSE tools; however, only the latter reaches the final planning step, notably the automatic production of a gradual public-building-stock energy renovation plan.

Table 1. Evaluation of selected tools with respect to energy efficiency planning pillars.

Tool	Key Capabilities	Planning Pillars Addressed	Limitations
EDUFOOTPRINT platform [29]	Quantitative evaluation of environmental footprint for various scenarios, taking into account life-cycle analysis; possibility to identify "green" interventions (with low emissions in the manufacturing stage); accounting for environmental impacts of renovation works during renovation; best-practices platforms: freely available/instant use; calculator: freely available for download after login and authorization by the webpage administrator.	P2–P4	The tool is restricted to single-building processing, thus cannot handle numerous buildings. It is limited to only one building type, namely, educational buildings. It does not provide a hierarchy of projects for various buildings and types. It cannot provide gradual renovation plans. The calculator is not instantly available, and the user should first register in the webpage and obtain access to the tool only after administrator authorization.
SISMA SET [30]	Performing techno-economical assessment for a single building; computation of advanced financial indicators, i.e., NPV, IRR; facilitates the formulation of financial schemes and defines the margins for the required subsidy; freely available/instant download.	P2, P4	The tool cannot manipulate numerous buildings. It partly tackles P3 by means of the manual inserting of KPIs for different solutions. The tool presumes already available state KPIs. It does not provide a hierarchy of projects for numerous buildings. Limited usability toward the production of gradual renovation plans.
PRIORITEE decision support tool (DST) [31]	A decision support tool (web app) to assess building stock energy performance, evaluate different efficiency and renewable interventions, and compare, rank and prioritize technical options through a set of key performance indicators (KPIs), including simple cost indicators such as energy costs, investment value, return of investment. Freely accessible only after login and authorization by the webpage administrator.	P1–P5	The tool addresses very well almost all pillars of energy planning. The main limitation is that the tool does not automatically provide a gradual renovation plan. Another limitation is that it is not instantly available, and the user should first register in the webpage and obtain access to the tool only after administrator authorization.
STEPPING EPC simulation tool [32]	The EPC simulation tool detects different investment scenarios to balance public and private interest in making the investment; the profitability of the investment is assessed by a number of specialized economic parameters such as profitability index, net present value, internal rate of return; the tool was designed to assess an investment plan of a building bundle. Freely available/instant use.	P3–P5	The tool provides a renovation investment plan accompanied with specialized cost indicators (NPV, IRR), as well as the required margin for subsidy. The tool manipulates numerous buildings and provides bundles of investments. The main restriction is that it presumes already available state KPIs in the base-case situation and for the various retrofit scenarios envisaged. It cannot automatically provide a gradual energy renovation plan.

Table 1. *Cont.*

Tool	Key Capabilities	Planning Pillars Addressed	Limitations
CESBA-MED toolkit [33]	This is a holistic tool belonging to the category of methods known as urban energy planning methods. It contains a large list of indicators that the user can choose, including climate, energy, environmental indicators, water, waste, etc. Provided that the urban processes and indicators are already available, the tool incorporates prioritization schemes of various renovation and strategies scenarios tackling public buildings' energy efficiency taking into account the interconnections with its environmental and system surroundings. Freely available/instant download.	P2–P5	The tool addresses well the pillars, provided that the required state KPIs are externally available. Although the tool is very useful for holistic policy making and strategy development for cities' sustainability, it presumes external calculation/production of state KPIs. Some of these KPIs and processes are considered advanced and require high-level skills from end users to use the tool properly. Does not automatically produce a gradual renovation plan for public buildings.
IMPULSE Excel-based tools [34,35]	The Excel-based tools provide the possibility to group the public building stock into representative typologies, to promptly produce KPIs for all the stock and to prioritize buildings and projects in a time horizon of up to 20 years; provided that the grouping of buildings is realistic, the KPIs' projection tool from representative buildings to the whole sample of buildings allows for the fast conducting of a realistic plan for gradual renovations in the following years. Freely available/instant download.	P2–P6	The tools adequately address almost all planning pillars. The main advantage is that the tools provide a gradual public building renovation plan that facilitates deciding on what projects to do, for which buildings and when. A key limitation is that they presume available state KPIs for the base-case and retrofit scenarios. They do not contain advanced financial indicators such as NPV or IRR; however, they predict a payback period, which is adequate, at least for practical planning purposes.

For the purposes of the present work, the IMPULSE set of tools are selected for further elaboration, taking into account also the following arguments:

- It is based on the typology-based approach, which is widely accepted by the scientific community for energy efficiency planning purposes, as advocated in the introduction section.
- It presents high replicability as it has already been widely used across the Mediterranean for the production of energy-mix plans at the local level. Indicatively, it has been tested in more than five EU Mediterranean regions and municipalities in the framework of the IMPULSE and IMPULSE-PLUS projects' implementation. It has been also used in planning activities in the framework of the SEACAP 4 SDG project, and it has been included in a training package in the framework of the meetMED project [36], both conducted for authorities located in the south Mediterranean region.
- In view of the case studied herein, it is recommended by MINENV the conducting of municipal building energy efficiency plans in the framework of L.4843/2021 (the IMPULSE tools are embedded in the ministry's webpage dedicated for local and regional plans for public building energy efficiency [27]).

2.2. The Selected Set of Tools

The IMPULSE set of tools includes three Excel-based tools, each one containing an extensive users' guide. Considering also that the toolset is already available in the project's deliverables database [25], the current presentation is restricted to the most important features of the tools.

2.2.1. The "Listing Public Buildings of Communities: Classification into Typologies and Corresponding Representative Buildings" Tool

For brevity, the term "PBT-Library" (PBT standing for public building typologies) is adopted as a "nickname" for this tool (direct download in ref. [34]). It is Excel based, which serves as a guide toward the recording of each building characteristic that influences energy performance and the classification of buildings into the so-called public building typologies (PBTs). Following the procedure described in Appendix A, the tool guides the user through the recording of energy-affecting characteristics of each building and the classification of the stock into building typologies. One representative building from each typology (preferably the one with the more available technical details) is selected as an ambassador building reflecting the performance of the rest of the buildings of the same typology.

2.2.2. The "KPIs' Processing" Tool

For brevity, herein the tool is called the "KPIs' processor". It is an Excel-based tool (direct download in ref. [34]) aimed at producing a state and impact KPI database for the base-case situation of the buildings and for various retrofit scenarios ranging from minor to deep retrofit. According to the instructions embedded in the tool, the "aggregative principle" regarding retrofit scenarios must be met, meaning that the more advanced scenarios (major and deep retrofit) are built on top of the less extensive ones (minor retrofit). For example, a sequence of minor and major retrofit scenarios including light replacement with LED fixtures and light replacement with LED fixtures plus the walls' thermal insulation, respectively, is indeed eligible for the IMPULSE tools. The tool extrapolates the inserted KPIs of ambassador buildings (produced by external means) to all buildings of each typology and to the whole building stock, hence providing energy, environmental and cost impacts for the various renovation scenarios. Its contents and key features are described in Appendix A.

2.2.3. The "KPIs-Processor's PLUG-IN"

The PLUG-IN (direct download in ref. [35]) automatically provides a renovation road map through elaborating on the KPI database produced before. Based on user-selected KPIs as decision-making criteria and their corresponding weights (contribution of each criterion in the objective function), as well as a preferred renovation rate per year, the tool yields a building renovation road map. The latter is presented in terms of projects per year accompanied by annual absolute and cumulative performance indicators such as the investment cost, the energy savings, CO_2 emissions avoidance and energy consumption cost savings. Its specific contents are presented in Appendix A.

2.3. Suggested Stepwise Planning Methodology

In this section, the tools presented previously are synthesized into a stepwise methodology for effective energy planning. The methodology is described in terms of its general use, as well as of its fitting with the Greek context regarding ongoing official directions concerning public buildings' energy efficiency plans at the local level. The approach consists of three methodological "layers" as follows:

- External resources and processing: it stands for an external source of data and information required as input conditions to the IMPULSE set of tools, referring to the resource categories below:
  - ○ Building stock data: for each building included in the examined building stock, data regarding key characteristics that influence energy performance are collected by available studies, building permit documentation or inspections.
  - ○ Ambassadors' KPIs: provided that the building stock has been classified into representative typologies following the procedure of the IMPULSE "PBT-Library" tool, the state KPIs of each ambassador building (one representative building of each typology) for the base case and for the various retrofit levels are extracted from external resources and used as inputs in the KPIs' processing tool.

- ○ Supporting material: it refers to additional external resources that may be needed for the generation of additional KPIs, for instance the primary energy and CO_2 emission conversion factors, energy technologies unit costs, etc.

The IMPULSE-required inputs and respective potential external resources and extraction processes are provided in Table 2.

Table 2. Potential resources of IMPULSE input parameters.

IMPULSE Tool	Input Parameters	Category	Potential Resources
PBT Library	• Building type/use • Construction year • No. of floors • Gross floor area • Construction type (depending on the construction materials) • Heating system • Cooling system	Building stock data	• Building permit documentation • Technical studies, drawings • Available EPC • Energy audit/inspection
KPIs' processor	For both the base case and the various retrofit levels, the following state KPIs are required for each ambassador building: • Total annual primary energy consumption • Annual final energy consumption per end-use (heating, cooling, etc.) • Annual final energy consumption per energy carrier (electricity, oil, RES, etc.) • Annual total and per energy carrier CO_2 emissions • Annual energy-consumption cost	Ambassadors' KPIs Supporting material	For the ambassador buildings identified after the classification process followed using the tool "PBT Library", the following possible resources may be exploited (it is strongly recommended that buildings with the maximum available information should be selected as ambassadors): • Available EPC • Possible actual data (energy bills or measurements) • Building energy simulation • Primary energy and emissions conversion factors found in official national reports or EPB technical directives • The energy-consumption cost may be derived based on the energy-carrier unit cost found from the relevant ongoing energy suppliers' prices
	For the various retrofit levels, the following additional KPIs are required: • Total investment cost • Simple payback period	Supporting material	• Energy technologies' unit purchase and installation cost, found in the relevant market, national reports or funding programs, etc., may be used for the estimation of the initial investment cost

- IMPULSE set of tools—general use: the steps presented in this layer indicate the sequence of using the tools in generalized terms, meaning that the tools can be applied for any country/region. The following methodological steps are suggested:
  - ○ Step-1: extraction of PBTs: after feeding the PBT-Library tool with the "Building stock data", and provided that appropriate classification ranges of input parameters are adopted, the tool provides guidance toward the development of a library of public-building typologies accompanied with details for one representative building (ambassador) of each typology.
  - ○ Step-2: production of the KPIs' database: it is produced using the KPIs' processing tool, as a result of inserting the ambassadors' KPIs provided by the previous

methodological layer. KPI databases are produced for the base case and the retrofit scenarios considered.
- ○ Step-3: generation of the building-stock renovation plan: being fed by the KPI database in step-2, the KPIs' processor PLUGIN, after setting up the decision-making scheme, provides a gradual renovation plan accompanied with suggested projects and energy, environmental and cost performance indicators on an annual basis.

The methodological steps and workflow processes are described in Table 3.

Table 3. IMPULSE-use methodological steps and expected outputs.

Methodological Step	IMPULSE Tool	Procedure	Expected Output
Step-1: Extraction of PBTs	PBT Library	• Insertion of inputs regarding the building-stock data in the worksheet "List of PB & CC_Absolute values". • Definition of appropriate ranges of building-stock data in the worksheet "Drop-down menus", hence transforming the building-stock inputs to classification criteria. • In the worksheet "List of Public Buildings & PBTs", the list of buildings is provided again along with building-stock data being inserted in terms of the ranges determined previously. • Selection of an ambassador building (one with maximum available information) from each PBT and provision of detailed description in the worksheets "Details for Ambassador".	• PBTs: library of public buildings and public-building typologies • Ambassadors: One representative building for each PBT
Step-2: Production of KPI database	KPIs' processor	• Insertion of the building stock (i.e. building name, floor area and no. of PBT) in the worksheet "Projection_Base-case". • Insertion of ambassadors' KPIs in the worksheets "base-case" and in the ones for the various retrofit levels, i.e., "minor-retrofit", etc.	• KPI database: for all buildings, the KPIs' data are produced for the base case and for the various retrofit levels in the respective projection sheets
Step-3: Generation of the building-stock renovation plan	KPIs-processor's PLUG-IN	Provision of the following inputs in the worksheet "MCA-INPUT": • Decision-making criteria and corresponding weights. • Optionally, bias may be imposed to a specific typology, level of retrofit or RES integration. • The desired floor area (%) to be renovated each year. • Selection of PBTs and levels of retrofit participating in the decision-making scheme.	• Ranking of all projects foreseen in the KPIs' processor. • Gradual renovation plan in terms of buildings and projects to be implemented annually, accompanied with impact indicators, i.e., energy savings, emissions avoidance, energy cost reduction, etc.

- Fitting to the Greek policy context: this layer refers to the specialization of the planning methodology in the Greek policy context. According to the ongoing legislation, public buildings' energy efficiency plans at regional or municipal level should be built upon concrete contents released by MINENV, particularly the following:
  - ○ Presentation of the building stock: this section may be easily completed by the synthesis of information between the available building-stock data and the tabulation and classification procedures in step-1 of the second layer above.

- ○ Techno-economic analysis of feasible retrofit scenarios, namely: (a) the minimum energy performance requirements scenario (MEPR); (b) the nZEB scenario. The recommended scenarios correspond to the major and deep retrofit levels foreseen by IMPULSE; hence, the required techno-economic analysis can be easily based on the KPI database produced by the KPIs' processor.
- ○ Prioritization of retrofitting scenarios based on techno-economic criteria.
- ○ Definition of a specific energy-saving goal and of projects' implementation road map.

The IMPULSE methodological aspects fitting to the ongoing Greek context are described in Table 4. A consolidated view of the proposed stepwise methodology is shown in Figure 1.

Table 4. IMPULSE fitting to the Greek policy context.

Content of the Energy-Efficiency Plan (Based on Legislation)	IMPULSE Tool	Procedure
Presentation of the building stock	PBT Library	Synthesis of information between the available building-stock data and the tabulation and classification procedures in step-1 of the second methodological layer above.
Techno-economic analysis of feasible retrofit scenarios	KPIs' processor	The MEPR and nZEB scenarios are analyzed for all ambassador buildings in the first methodological layer. The obtained KPIs are then provided in the IMPULSE tool, as major (MEPR) and deep (nZEB) retrofits. The produced KPI database for the whole building stock can be elaborated on for techno-economic analysis presentation.
Prioritization of retrofitting scenarios	KPIs-processor's PLUGIN	Based on the setup of the decision-making scheme, the tool provides a ranking of all projects for all buildings, as well as a gradual renovation plan associated with the expected absolute and cumulative energy savings. The outcome stands for the required energy-saving goal together with the presentation of a projects' implementation road map.
Definition of a specific energy-saving goal and of a projects' implementation road map		

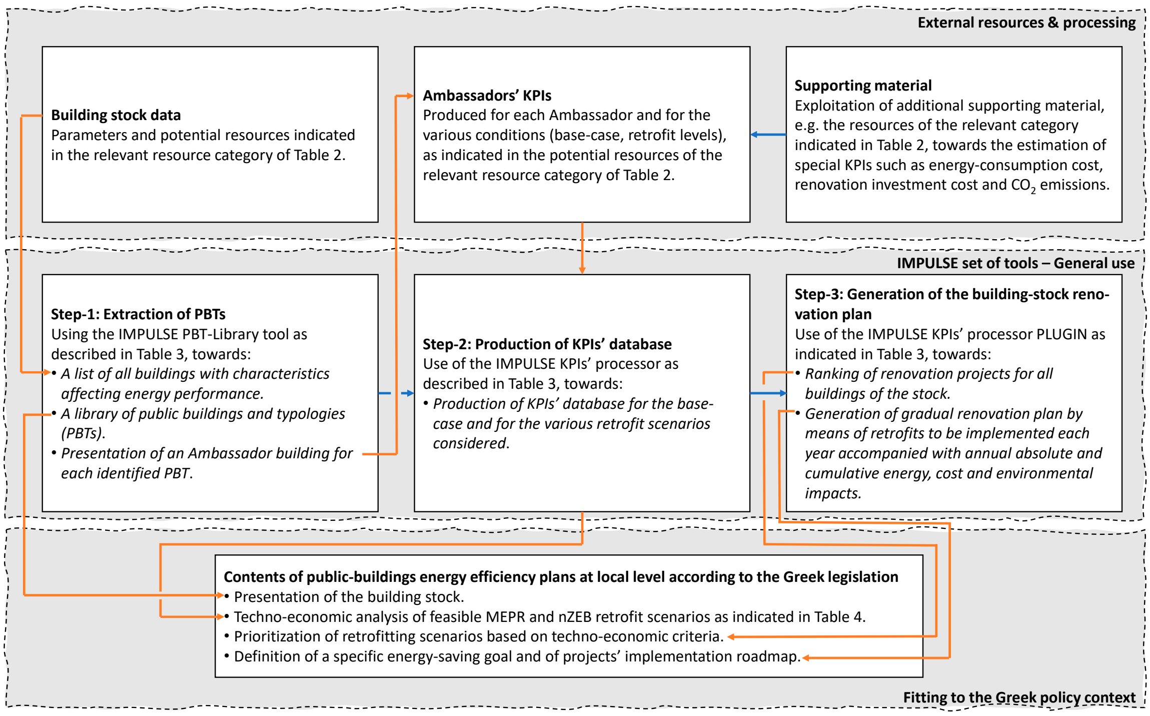


Figure 1. Methodological flow diagram of the suggested approach for public buildings' energy efficiency planning using the IMPULSE project set of tools (blue lines: information flow in the same methodological layer; orange lines: information flow between different methodological layers).

2.4. The Case Study Considered

The case study considered herein refers to 10 priority public buildings owned by the Municipality of Aigialeia. The municipality is located in the region of western Greece in the northern Peloponnese. According to the Greek EPBD, the municipality belongs to the "B" climate zone out of the four climatic zones of Greece. The area has a typical Mediterranean climate characterized by hot summers and humid but mild winters. January is the coldest month; however, maximum precipitation takes place in November. July stands for the hottest month with the highest amounts of solar irradiance.

The municipality has already signed the Covenant of Mayors (CoM) and has officially adhered to the initiative since 6 February 2015. It has completed a sustainable energy action plan (SEAP), which outlines a series of actions, indicatively energy upgrading of municipal buildings, replacement of street lighting, modernization of the municipal fleet with less-polluting vehicles, exploitation of renewable energy sources (RES), informing and awareness raising, improvement of urban transport and others, toward the achievement of the CO_2 emission reduction target. Despite its low contribution in the energy mix, the public building stock is regarded by the municipality as one of the most essential policy sectors to promote energy efficiency interventions. Indeed, in 2019 the municipality completed an action plan for prioritizing municipal buildings by means of a simple score function taking into account the building use, the operation schedule (building-use frequency) and the number of users. Based on the scoring procedure, 10 priority buildings (out of 81 public buildings) were determined, for which, however, only RES (particularly, grid-connected PVs) interventions are proposed in the framework of the action plan. The municipality is interested in identifying more holistic investments for these buildings, hence motivating the current research. The 10 priority buildings, situated in various locations throughout the municipality (refer to Figure 2) are the following:

- First professional high school of Aigio;
- Municipal office of Akrata;
- Municipal office of Sympoliteia;
- Municipal office of Aigeira;
- Municipal office of Diakopto;
- First elementary school of Aigio;
- Second elementary school of Aigio;
- First junior high school of Aigio;
- High school of Akrata;
- First senior high school of Aigio.

Figure 2. The 10 priority buildings of the Municipality of Aigialeia (screenshot from Google Earth).

The most important technical parameters influencing energy performance are collected and provided in the "PBT-Library" tool following step-1 of the suggested planning methodology. The information of the collected typical parameters is presented in Figure 3 in terms of the completed worksheet, the "List of PB & CC_Absolute values", of the aforementioned tool.

Building No	Building name	Building floor area (m^2)	Absolute values of Classification Criteria (CC) (previous to PBT classification)						
			Building type / use	Nº of floors	Construction type			Heating system	Cooling system
					Roof geometry	Roof material	Structure/ Framework		
1	1st professional highschool of Aigio	6832	A or B level education	1	Inclined	Roman tiles	Reinforced concrete-bricks	Oil boiler	Local A/C units
2	Municipal office of Akrata	200	Office	1	Inclined	Roman tiles	Masonry	Oil boiler	Local A/C units
3	Municipal office of Sympoliteia	660	Office	2	Inclined	Roman tiles	Masonry	Oil boiler	Local A/C units
4	Municipal office of Aigeira	140	Office	2	Horizontal	Concrete-based conventional type	Masonry	Oil boiler	Local A/C units
5	Municipal office of Diakopto	440	Office	2	Horizontal	Concrete-based conventional type	Reinforced concrete-bricks	Oil boiler	Local A/C units
6	1st Elementary school of Aigio	770	A or B level education	2	Horizontal	Concrete-based conventional type	Reinforced concrete-bricks	Oil boiler	Local A/C units
7	2nd Elementary school of Aigio	1100	A or B level education	2	Horizontal	Concrete-based conventional type	Reinforced concrete-bricks	Oil boiler	Local A/C units
8	1st junior highschool of Aigio	1850	A or B level education	2	Horizontal	Concrete-based conventional type	Reinforced concrete-bricks	Oil boiler	Local A/C units
9	Junior highschool of Akrata	1115	A or B level education	1	Inclined	Roman tiles	Masonry	Oil boiler	Local A/C units
10	1st senior highschool of Aigio	4450	A or B level education	3	Horizontal	Roman tiles	Reinforced concrete-bricks	Oil boiler	Local A/C units

Figure 3. The 10 priority buildings' energy-influencing characteristics completed in the IMPULSE "PBT-Library" tool (screenshot from the tool).

The current work focuses on the application of the suggested planning methodology, specifically the steps presented previously regarding the application of the IMPULSE project set of tools (notably, the "IMPULSE set of tools—general use" layer introduced in the previous section) toward the development of a reliable energy efficiency plan for the selected priority buildings. The final projects' road map is developed based on a sensitivity analysis conducted in the KPIs processor's PLUGIN for different combinations of decision-criteria weights in relation to the municipal authority's requirements, which are the following:

- As decision criteria, the following KPIs and desired states are adopted:
  - ○ Total annual primary energy savings (the highest possible);
  - ○ Total annual avoided CO_2 emissions (the highest possible);
  - ○ Investment cost (the least possible (per project));
- Desired duration of the plan (until deep retrofit of all buildings): 6 years;
- Number of buildings retrofitted per year: at least two.
- **Balanced road map with similar number of projects implemented each year.**

3. Results

3.1. Classification of the Building Stock

According to the presented methodology, the first step is to identify the most relevant range for each classification criteria toward a realistic clustering of the building stock. Considering the absolute values of building-stock data (refer to Figure 3) for the case studied, the following clustering ranges are adopted and imposed in the worksheet "Dropdown menus" of the "PBT-Library" tool:

- Building use. Taking into account the recorded uses, as well as the fact that, according to the Greek EPBD, the A (elementary) and B (high school) education levels have the same operation schedules, load sources and minimum operation requirements, the following building uses are identified:
  - ○ A or B education level;
  - ○ Office.

- Number of floors. This relates mainly to the effect of roof interventions on the overall building energy performance. As per other research [37,38], low-rise buildings are considered those with fewer than three floors. In this regard, the following classification ranges are adopted:
    - Up to three floors (low-rise);
    - Four to six floors;
    - Above six floors.
- Construction type. Apart from the thermal transmittance, a building envelope's structure materials determine the building's thermal inertia. Following the Greek EPBD classification, the following options are adopted:
    - Light/medium structure (e.g., metallic);
    - Heavy structure (concrete, brick wall);
    - Very heavy structure (e.g., masonry).
- Heating system. This is an essential parameter since it defines the efficiency of ensuring thermal comfort conditions in winter, as well as the energy source consumed to cover the related energy demand. The following options are adopted:
    - Oil boiler-burner (central system);
    - Central heat pump;
    - None exist.
- Cooling system. It is related to the energy source consumed to compensate for the cooling loads in the summer period. The following options are adopted:
    - Local heat pump (regular A/C split units);
    - Central heat pump;
    - None exist or are limited.

Based on the above, the classification process applied for the considered building stock resulted in the four public-building typologies (PBTs) tabulated in Figure 4. (results obtained in the worksheet "List of Public Buildings & PBTs" of the PBT-Library tool). As far as the ambassador buildings are concerned, the following are selected (according to the available information and the preferences of the municipality):

- PBT1 ambassador: second elementary school of Aigio;
- PBT2 ambassador: municipal office of Sympoliteia;
- PBT3 ambassador: municipal office of Diakopto;
- PBT4 ambassador: junior high school of Akrata.

Building No	Building name	Classification Criteria (CC) into Public Building Typologies (PBT)					Public Building Typology (PBT)
		Building type / use (CC1)	Nº of floors (CC3)	Construction type (CC5)	Heating system (CC6)	Cooling system (CC7)	
1	1st professional highschool of Aigio	A or B level education	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT1
2	Municipal office of Akrata	Office	<=3	Very heavy structure (e.g. masonry)	Oil boiler	Local heat pump	PBT2
3	Municipal office of Sympoliteia	Office	<=3	Very heavy structure (e.g. masonry)	Oil boiler	Local heat pump	PBT2
4	Municipal office of Aigeira	Office	<=3	Very heavy structure (e.g. masonry)	Oil boiler	Local heat pump	PBT2
5	Municipal office of Diakopto	Office	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT3
6	1st Elementary school of Aigio	A or B level education	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT1
7	2nd Elementary school of Aigio	A or B level education	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT1
8	1st junior highschool of Aigio	A or B level education	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT1
9	Junior highschool of Akrata	A or B level education	<=3	Very heavy structure (e.g. masonry)	Oil boiler	Local heat pump	PBT4
10	1st senior highschool of Aigio	A or B level education	<=3	Heavy structure (concrete, brick-wall)	Oil boiler	Local heat pump	PBT1

Figure 4. Classified stock of the 10 priority buildings of the Municipality of Aigialeia (screenshot from the PBT-Library tool).

3.2. Ambassador-Buildings' (External) Energy Analysis

As described in Section 2, the production of state KPIs for each ambassador building and for each situation (including the base case and the various retrofit levels and scenarios) precedes the use of the KPIs' processor. In compliance with the "aggregative principle" and considering the Greek legal framework in relation to the MEPR and nZEB scenarios, the corresponding interventions assumed for the major (MEPR) and the deep (nZEB) retrofit levels for all the ambassador buildings are tabulated in Table 5.

Table 5. Energy retrofit scenarios considered for the selected ambassador buildings.

Interventions	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 [1] IMPULSE-Wise Retrofit Level: Major	Scenario 3 [1] IMPULSE-Wise Retrofit Level: Deep
Envelope interventions	✔	✔	✔
Roof thermal insulation: graphite-based EPS 7 cm	✓	✓	✓
Wall thermal insulation: graphite-based EPS 7 cm	✓	✓	✓
Windows replacement: low-e double-glazed 4-18-4 mm, aluminum frame with thermal break	✓	✓	✓
Systems' interventions	-	✔	✔
Installation of a central heat-pump for heating and cooling	-	✓	✓
Fixtures' replacement with LED (prescribed based on lumens minimum requirements)	-	✓	✓
RES integration	-	-	✔
Grid-connected PV (installed power prescribed based on the electricity demand after energy efficiency interventions)	-	-	✓

[1] Built on top of the former scenario.

Working on the external processing "layer" according to the procedure of Figure 1, for building energy analysis purposes, the quasi-steady calculation method has been adopted based on the EN 13790 standard using the national software TEE KENAK v.1.31. For the base-case situation and for each of the three retrofit scenarios considered, the calculation procedure yields state the KPIs' results including total and per end-use primary energy consumption, final energy consumption per end use and per carrier and CO_2 emissions per energy carrier.

Cost indicators, i.e., the investment cost and energy-related cost (expense), are calculated on the basis of typical unit costs found in ref. [27] for the Greek context. Concerning the photovoltaics (PV) measure, it is handled as grid-connected under the single net-metering mechanism while cost reduction that is due to PV contribution is calculated following the procedure and electricity unit cost provided in ref. [39]. A view of the building performance estimated under each renovation scenario (described in Table 5.) for the ambassador buildings is provided in Tables 6–9.

The following results are tabulated:

- Energy consumption per carrier, obtained by the simulation software;
- Annual total CO_2 emissions, obtained by the simulation software;
- Investment cost, obtained using typical interventions' unit costs found in ref. [27] for the Greek context;
- Annual energy cost, obtained on the basis of the ongoing energy supply unit cost (EUR/kWh) in Greece [39];
- Simple payback period, calculated as the period (in years) after which the annual cumulative cash flow becomes positive;
- Annual cumulative cash flow, calculated as the sum of the previous year cumulative cash flow and the ongoing year net cash flow being the energy-cost savings achieved because of the annual energy saving (assumed constant).

Table 6. State KPIs for the PBT1′s ambassador building in the base case and for the retrofit scenarios.

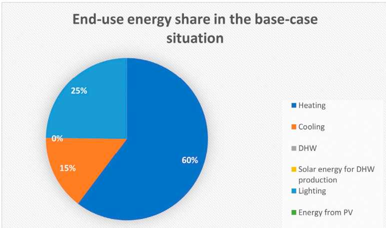
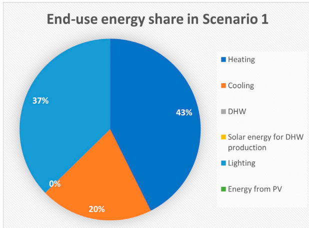
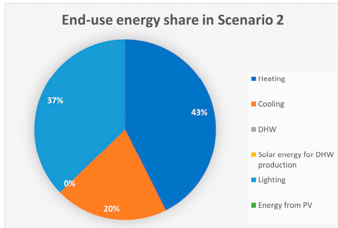
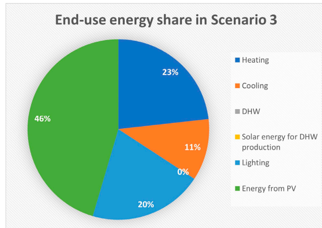
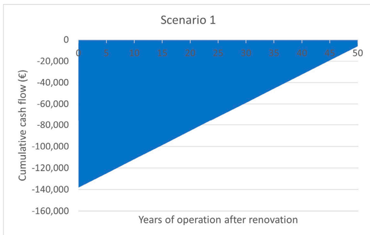
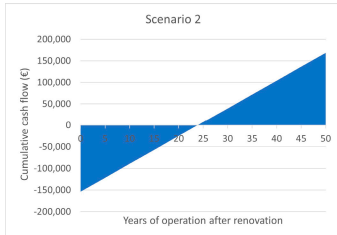
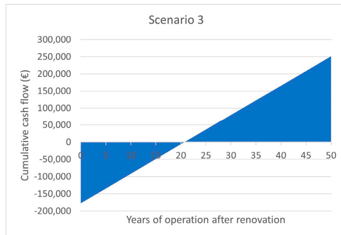
KPI	Base-Case Situation	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 IMPULSE-Wise Retrofit Level: Major	Scenario 3 IMPULSE-Wise Retrofit Level: Deep
Electricity consumption (kWh/m^2)	20.4	19.6	12.0	2.0
Fossil fuel consumption (for heating purposes) (kWh/m^2)	31.0	14.6	0.0	0.0
RES consumption (kWh/m^2)	0.0	0.0	0.0	10.0
End-use energy share				
Annual total emissions CO_2 (kg/m^2)	20.5	15.7	7.2	1.2
Investment cost (EUR)	Not applicable	138,263.0	153,862.0	177,807.0
Annual energy cost (EUR)	9369.0	6724.0	2765.0	462.0
Simple payback period (yrs)	Not applicable	>50	23.9	20.7
Annual cumulative cash flow (EUR)	Not applicable			

Table 7. State KPIs for the PBT2's ambassador building in the base case and for the retrofit scenarios.

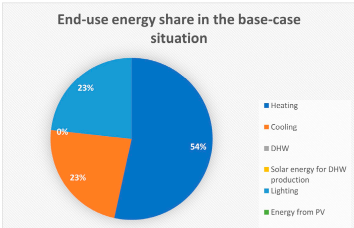
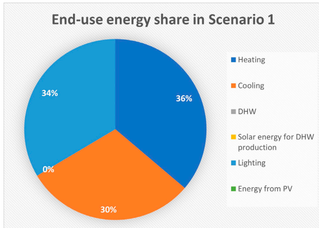
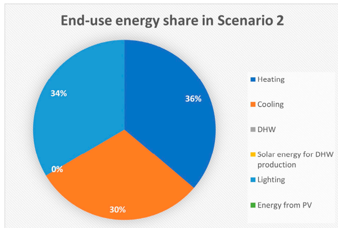
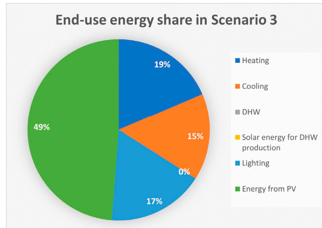
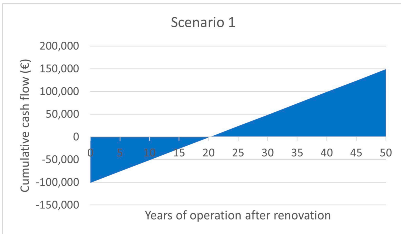
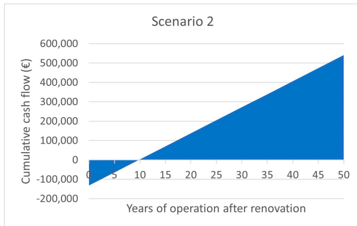
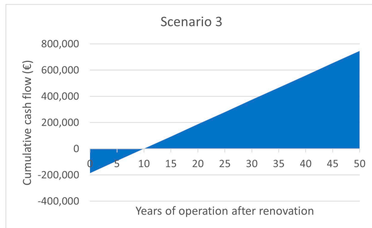
KPI	Base-Case Situation	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 IMPULSE-Wise Retrofit Level: Major	Scenario 3 IMPULSE-Wise Retrofit Level: Deep
Electricity consumption (kWh/m^2)	81.0	77.0	42.2	2.0
Fossil fuel consumption (for heating purposes) (kWh/m^2)	93.0	43.7	0.0	0.0
RES consumption (kWh/m^2)	0.0	0.0	0.0	40.2
End-use energy share				
Annual total emissions CO_2 (kg/m^2)	73.4	57.9	25.5	1.2
Investment cost (EUR)	Not applicable	101,383.0	131,651.0	185,640.0
Annual energy cost (EUR)	19,609.0	14,605.0	5853.0	277.0
Simple payback period (yrs)	Not applicable	20.3	9.8	10.0
Annual cumulative cash flow (EUR)	Not applicable			

Table 8. State KPIs for the PBT3's ambassador building in the base case and for the retrofit scenarios.

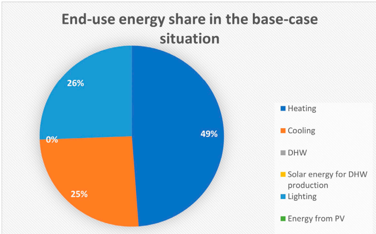
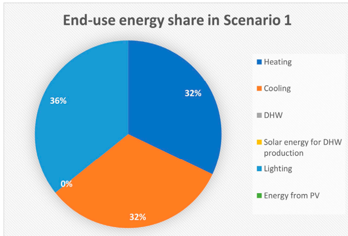
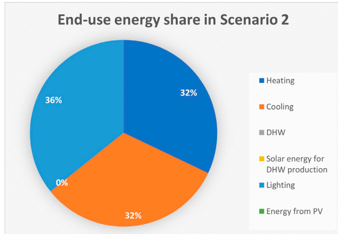
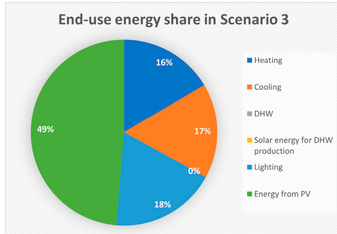
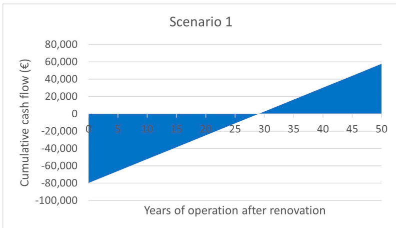
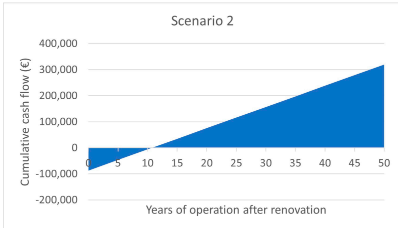
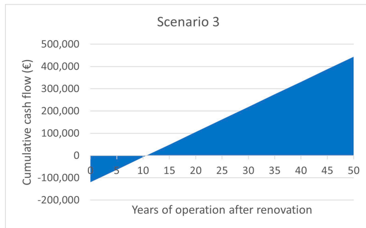
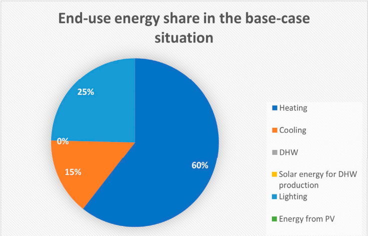
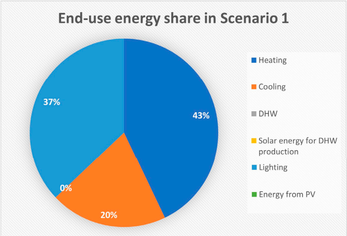
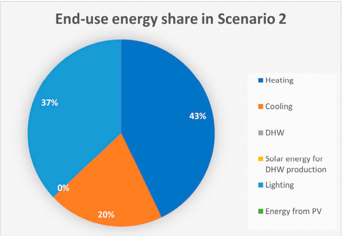
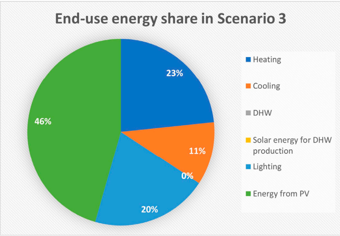
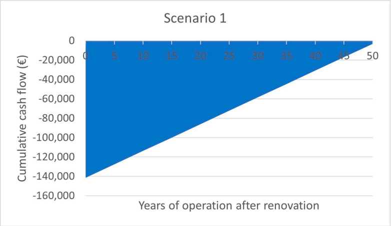
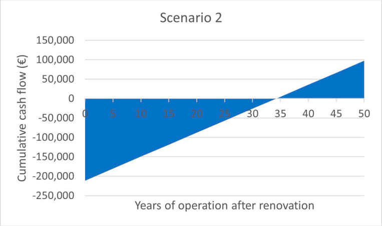
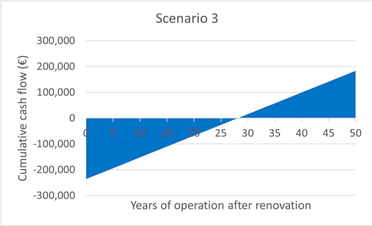
KPI	Base-Case Situation	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 IMPULSE-Wise Retrofit Level: Major	Scenario 3 IMPULSE-Wise Retrofit Level: Deep
Electricity consumption (kWh/m^2)	78.6	74.7	38.5	2.0
Fossil fuel consumption (for heating purposes) (kWh/m^2)	75.0	35.3	0.0	0.0
RES consumption (kWh/m^2)	0.0	0.0	0.0	36.5
End-use energy share				
Annual total emissions CO_2 (kg/m^2)	67.2	54.3	23.2	1.2
Investment cost (EUR)	Not applicable	79,836.0	87,431.0	120,142.0
Annual energy cost (EUR)	11,769.0	9018.0	3555.0	185.0
Simple payback period (yrs)	Not applicable	29.0	10.7	10.7
Annual cumulative cash flow (EUR)	Not applicable			

Table 9. State KPIs for the PBT4's ambassador building in the base case and for the retrofit scenarios.

KPI	Base-Case Situation	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 IMPULSE-Wise Retrofit Level: Major	Scenario 3 IMPULSE-Wise Retrofit Level: Deep
Electricity consumption (kWh/m^2)	20.8	20.0	12.3	2.0
Fossil fuel consumption (for heating purposes) (kWh/m^2)	32.0	15.0	0.0	0.0
RES consumption (kWh/m^2)	0.0	0.0	0.0	10.3
End-use energy share				
Annual total emissions CO_2 (kg/m^2)	21.0	16.0	7.4	1.2
Investment cost (EUR)	Not applicable	141,491.0	211,356.0	236,289.0
Annual energy cost (EUR)	9743.1	6978.0	2873.0	468.0
Simple payback period (yrs)	Not applicable	>50	34.2	28.1
Annual cumulative cash flow (EUR)	Not applicable			

The above represent a part of the ambassadors' KPIs, which are used as inputs in the IMPULSE KPIs' processor toward the production of the KPI database for all buildings of the stock. Focusing more on the ambassador buildings, the above results dictate that a significant environmental impact may be achieved under the deep retrofit (nZEB) scenario ranging from 94–98% CO_2 emissions avoidance for the studied ambassadors. It is also seen that despite the higher investment cost for the nZEB scenario of the office buildings (PBT2 and PBT3), the payback period is significantly lower compared to the same renovation scenario for the school buildings (PBT1 and PBT4). In any case, the investment for all buildings becomes more affordable when at least the heating/cooling and lighting systems are upgraded on top of the "hard" investments regarding thermal insulation. As expected, the office buildings present better economic performance compared to school buildings because of the long no-operation periods (e.g., in summer) of the latter.

3.3. Production of Building Stock KPIs' Database

The previously obtained ambassadors' KPIs are fed back to the "IMPULSE set of tools" methodological layer according to the procedure described in Figure 1. Specifically, in step-2 of the IMPULSE methodology, the KPIs are inserted in the appropriate KPIs' processor worksheets referring to the ambassador buildings. A sample of inserted KPIs for the base case and the deet retrofit level for the PBT1 ambassador (refer to Table 6) is given in Figure 5. It is noted that the tool allows for up to three scenarios for any retrofit level, which means that, in total, up to 12 scenarios may be processed. In the case studied herein, only one scenario is considered for each level of retrofit, namely medium, major and deep retrofit. As mentioned in Appendix A, the tool also automatically suggests the best among the up to three scenarios of each retrofit level based on the indicator "Total investment cost per total annual energy saved"; hence, it consults the user to select the best scenario for each level of retrofit afterward in the projection worksheets. Obviously, since in the case studied herein only one scenario is assumed for each retrofit level, scenario 1 is always selected in the aforementioned projection worksheets.

Finally, for the various building-stock situations (base case, minor, medium, major, deep retrofit) the KPIs' processor provides the state and impact KPIs for each building, as well as the consolidated values of KPIs for each PBT separately and overall for the whole building stock. A sample of the produced KPIs' results referring to the whole building stock is presented in Table 10. The energy, environmental and economic impacts for each retrofit level/scenario for the whole building stock are illustrated in Figure 6. It is seen that, as moving toward deep retrofitting, CO_2 emissions are reduced by 95% compared to the existing situation, with a similar reduction in annual energy cost. The payback period is significantly reduced in the deep retrofit scenario as a result of energy-consumption compensation from the foreseen PVs. As far as the investment cost is concerned, the deep-renovation cost for all buildings is almost EUR 3 M, which is around EUR 800 k more than the medium retrofit cost.

Table 10. Calculated KPIs in the base case and for the retrofit scenarios for the whole building stock.

KPI	Base-Case Situation	Scenario 1 IMPULSE-Wise Retrofit Level: Medium	Scenario 2 IMPULSE-Wise Retrofit Level: Major	Scenario 3 IMPULSE-Wise Retrofit Level: Deep
Electricity consumption (kWh)	444,816.8	426,691.4	252,441.0	35,114.0
Fossil fuel consumption (for heating purposes) (kWh)	626,742.0	294,568.7	0.0	0.0
Annual total emissions CO_2 (tns)	433.5	334.9	152.1	21.2
Investment cost (k EUR)	-	2260.6	2596.6	3062.7
Annual energy cost (k EUR)	179.0	129.8	53.0	7.4
Simple payback period (yrs)	-	46.0	20.6	17.8

KPIs for the base-case scenario		Ambassador_PBT1
Building name		2nd Elementary school of Aigio
Building floor area (m^2)		1100
Annual electricity consumption	kWh/m^2/yr	20.40
	kWh/yr	22,440.00
Annual consumption of fossil fuel	kWh/m^2/yr	31.00
	kWh/yr	34,100.00
Annual generation of Renewable Energy	kWh/m^2/yr	0.00
	kWh/yr	0.00
Total annual CO_2 emissions	kg/m^2/yr	20.48
	kg/yr	22,526.99
Annual total energy-related operational cost	National Currency/m^2/yr	8.52
	National Currency/yr	9 369.42

KPIs for the deep-retrofit scenarios		Ambassador_PBT1		
Retrofit scenario		Scenario1_PBT1	Scenario2_PBT1 (optional)	Scenario3_PBT1 (optional)
Building name		2nd Elementary school of Aigio		
Building floor area (m^2)		1100		
Annual electricity consumption	kWh/m^2/yr	2.00		
	kWh/yr	2 200.00	0.00	0.00
Annual consumption of fossil fuel	kWh/m^2/yr	0.00		
	kWh/yr	0.00	0.00	0.00
Annual generation of Renewable Energy	kWh/m^2/yr	9.97		
	kWh/yr	10,968.93	0.00	0.00
Total annual CO_2 emissions	kg/m^2/yr	1.21		
	kg/yr	1 325.94	0.00	0.00
Annual total energy-related operational cost	National Currency/m^2/yr	0.42		
	National Currency/yr	462.00	0.00	0.00
Total investment cost	National Currency	177,807.47		
Simple Payback period	yr	20.70		

Figure 5. Sample of PBT1 ambassador's KPIs inserted in the IMPULSE KPIs' processor (screenshot from the tool; clarification: white cells: inserted; colored cells: automatically calculated in the tool).

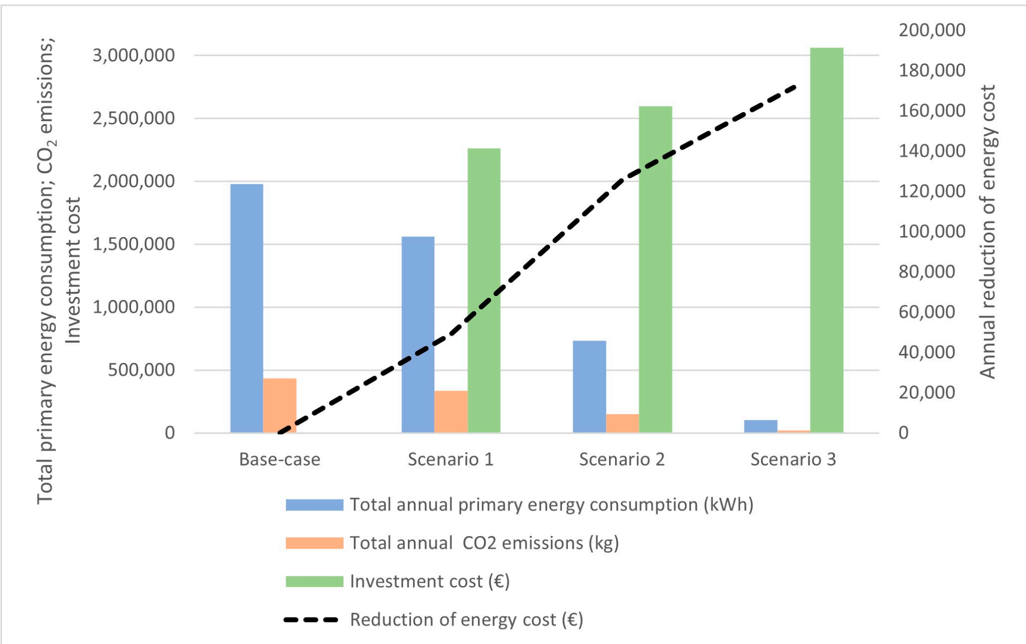


Figure 6. Energy, environmental and economic impacts for the various renovation scenarios studied for the whole building stock.

3.4. Production of the Building Stock Energy Efficiency Road Map

In the final step, the "KPIs' processor PLUGIN" tool is used for producing the renovation road map following step-3 of the suggested methodology. According to the municipal authority's preferences (refer to Section 2.4), the following decision criteria are adopted:

- DC1: total annual primary energy savings;
- DC2: annual avoidance of CO_2 emissions;
- DC3: investment cost.

The corresponding weights are defined following a sensitivity analysis in view of the municipal authority's preferences reported in Section 2.4. In total, six combinations of weights of decision criteria are tested in the tool, providing the alternative renovation road maps presented in detail in Appendix B. The indices that compile the authority's preferences for the different weights' combinations are presented in Table 11. First of all, it is observed that the combinations with the same sum of DC1 and DC2 weights provide exactly same results because of the similar nature and strong interrelation between the two criteria. Combinations comb3 and comb4 are rejected as they present the least compatibility with the authority's goals (more than the desired plan duration, not a balanced no. of projects). Combinations comb1, comb2, comb5 and comb6 achieve the required duration of the renovation plan (6 years). However, despite of the best distribution of projects through the years achieved by combinations comb5 and comb6 (because of the lowest standard deviation of project numbers), combinations comb1 and comb2 ensure more than just one building is retrofitted each year for the first 5 years of implementation. As far as the energy savings are concerned, Figure 7 illustrates that comb1 (or comb2) ensures the highest cumulative primary-energy savings per year in comparison to the ones obtained by the other weights' combinations (refer also to Appendix B).

Table 11. Combinations of weights tested in the PLUGIN tool and corresponding preferences' indices.

Combination	Weights	Road Map Duration (yrs)	Standard Deviation of Projects' Number	No. of Years with at Least Two Buildings Being Retrofitted
Comb1	DC1: 30% DC2: 10% DC3: 60%	6	1.03	5
Comb2	DC1: 10% DC2: 30% DC3: 60%	6	1.03	5
Comb3	DC1: 60% DC2: 10% DC3: 30%	7	1.91	2
Comb4	DC1: 10% DC2: 60% DC3: 30%	7	1.91	2
Comb5	DC1: 30% DC2: 60% DC3: 10%	6	0.82	3
Comb6	DC1: 60% DC2: 30% DC3: 10%	6	0.82	3

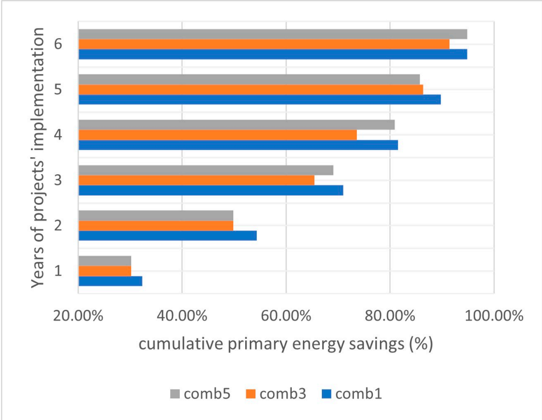
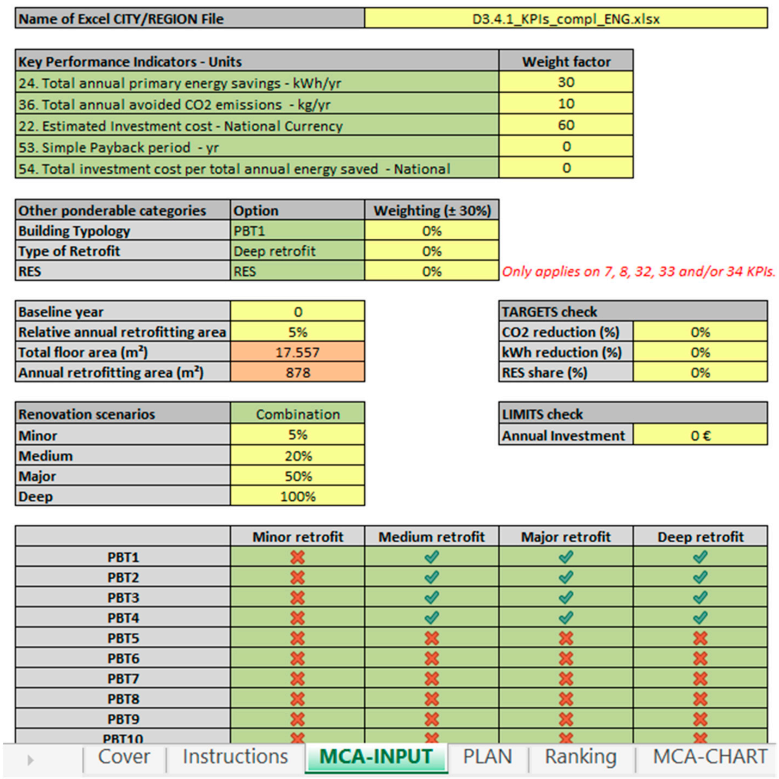


Figure 7. Cumulative primary energy savings for each year of project implementation obtained for the different combinations of decision criteria weights.

Based on the sensitivity analysis above, the combination comb1 is adopted for the case study, and the following setup is inserted in the PLUGIN tool (refer to Figure 8):

- Decision criteria and respective weights:
    - ○ Total annual primary energy savings/weight: 30%;
    - ○ Total annual avoided CO_2 emissions/weight: 10%;
    - ○ Estimated investment cost/weight: 60%;
- No bias is imposed on a specific typology, retrofit level or RES integration;
- Desired floor area renovated annually: 5% of the whole building stock floor area;
- KPIs' database objective participated in the MCA processing: all retrofit levels for all four PBTs, except the minor retrofit level because it is not at all included in the retrofit scenarios studied.



Name of Excel CITY/REGION File	D3.4.1_KPIs_compl_ENG.xlsx

Key Performance Indicators - Units	Weight factor
24. Total annual primary energy savings - kWh/yr	30
36. Total annual avoided CO2 emissions - kg/yr	10
22. Estimated Investment cost - National Currency	60
53. Simple Payback period - yr	0
54. Total investment cost per total annual energy saved - National	0

Other ponderable categories	Option	Weighting (± 30%)	
Building Typology	PBT1	0%	
Type of Retrofit	Deep retrofit	0%	
RES	RES	0%	*Only applies on 7, 8, 32, 33 and/or 34 KPIs.*

Baseline year	0
Relative annual retrofitting area	5%
Total floor area (m²)	17.557
Annual retrofitting area (m²)	878

TARGETS check	
CO2 reduction (%)	0%
kWh reduction (%)	0%
RES share (%)	0%

Renovation scenarios	Combination
Minor	5%
Medium	20%
Major	50%
Deep	100%

LIMITS check	
Annual Investment	0 €

	Minor retrofit	Medium retrofit	Major retrofit	Deep retrofit
PBT1	✗	✓	✓	✓
PBT2	✗	✓	✓	✓
PBT3	✗	✓	✓	✓
PBT4	✗	✓	✓	✓
PBT5	✗	✗	✗	✗
PBT6	✗	✗	✗	✗
PBT7	✗	✗	✗	✗
PBT8	✗	✗	✗	✗
PBT9	✗	✗	✗	✗
PBT10	✗	✗	✗	✗

Cover | Instructions | MCA-INPUT | PLAN | Ranking | MCA-CHART

Figure 8. Multi-criteria assessment scheme setup for the considered building stock of the Municipality of Aigialeia (screenshot from the KPI processor's PLUGIN tool).

The results obtained are provided in Figure 9. A 6-year renovation plan emerged, ensuring a road map of gradual renovation of all buildings until their deep renovation, which is compatible with the authority's requirements.

ANNUAL RETROFIT PLAN					
		Years	1	2	3
Annual	Floor area retrofitted	m²	6,942	4,580	980
Annual	Annual investment	NC	1,162,994	739,936	289,432
Annual	Savings - currency	NC/yr	59,757	39,869	29,236
Annual	Savings - CO2	tCO2/yr	141	96	72
Annual	Savings - kWh	kWh/yr	640,782	435,284	329,561
Accumulated	Floor area retrofitted	m²	6,942	11,522	12,502
Accumulated	Investment	NC	1,162,994	1,902,931	2,192,362
Accumulated	Savings - currency	NC/yr	59,757	99,627	128,863
Accumulated	Savings - CO2	tCO2/yr	141	237	309
Accumulated	Savings - kWh	kWh/yr	640,782	1,076,066	1,405,627
	Share of PEC from RE	%	5.09%	7.65%	9.26%
		1	PBT2 - Municipal office of Aigeira - Medium Retrofit	PBT2 - Municipal office of Aigeira - Deep retrofit	PBT2 - Municipal office of Akrata - Deep retrofit
		2	PBT2 - Municipal office of Aigeira - Major Retrofit	PBT2 - Municipal office of Akrata - Major Retrofit	PBT2 - Municipal office of Sympoliteia - Deep retrofit
		3	PBT2 - Municipal office of Akrata - Medium Retrofit	PBT1 - 1st senior highschool of Aigio - Deep retrofit	PBT3 - Municipal office of Diakopto - Major Retrofit
		4	PBT1 - 1st professional highschool of Aigio - Deep retrofit		
		Years	4	5	6
Annual	Floor area retrofitted	m²	2,070	1,870	1,115
Annual	Annual investment	NC	331,751	302,273	236,289
Annual	Savings - currency	NC/yr	18,351	15,143	9,275
Annual	Savings - CO2	tCO2/yr	45	36	22
Annual	Savings - kWh	kWh/yr	208,339	163,550	100,038
Accumulated	Floor area retrofitted	m²	14,572	16,442	17,557
Accumulated	Investment	NC	2,524,114	2,826,387	3,062,676
Accumulated	Savings - currency	NC/yr	147,214	162,357	171,631
Accumulated	Savings - CO2	tCO2/yr	354	390	412
Accumulated	Savings - kWh	kWh/yr	1,613,966	1,777,517	1,877,554
	Share of PEC from RE	%	10.57%	11.34%	11.56%
		1	PBT3 - Municipal office of Diakopto - Deep retrofit	PBT1 - 1st Elementary school of Aigio - Major Retrofit	PBT4 - Junior highschool of Akrata - Deep retrofit
		2	PBT1 - 1st junior highschool of Aigio - Deep retrofit	PBT1 - 1st Elementary school of Aigio - Deep retrofit	
		3		PBT1 - 2nd Elementary school of Aigio - Deep retrofit	

Figure 9. The produced renovation road map for the considered building stock (screenshot from the KPIs processor's PLUG-IN).

In a graphical form, the annual performance (not cumulative) of the planned projects is shown in Figure 10. The produced plan reveals the following cumulative result by the end of foreseen projects' implementation: primary energy saving of approx. 1877 MWh; CO_2 emissions avoidance of around 412 tns; energy-consumption cost savings of more than EUR 170,000.

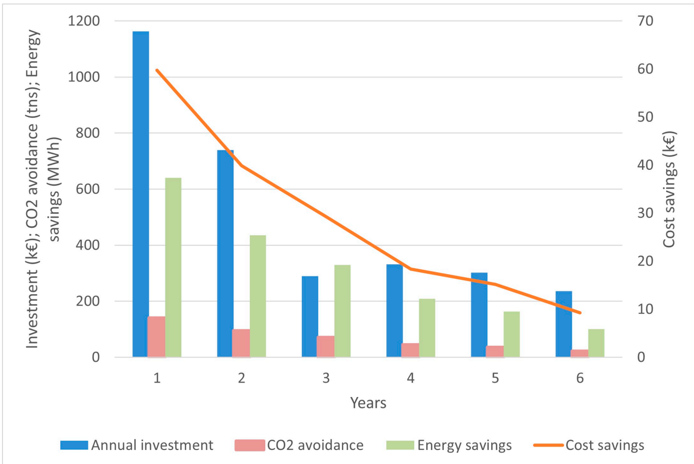


Figure 10. Annual performance of the suggested gradual renovation plan for the studied building stock.

4. Discussion

Planning the energy efficiency of public buildings at the local level presents many challenges and complexities mainly regarding the highly demanding and often complex management activities ranging from data collection to the definition of projects to be implemented in the near future. The presented work evaluated numerous tools developed in the framework of the Interreg MED 2014–2020 program and discussed their capabilities in addressing important challenges of energy efficiency planning activities.

Considering its capabilities, the IMPULSE Interreg MED project's set of tools was further elaborated and synthesized into a general stepwise methodology for public buildings' energy efficiency planning purposes. The introduced methodology can be easily employed in various EU regions and worldwide, considering that region-specific parameters are defined externally and then provided to the tools. Indeed, the PBT-Library tool allows for user-defined classification criteria and ranges and simply guides the user through the clustering procedure based on common criteria ranges toward grouping into representative typologies. The KPIs' processing tool is independent of regional/local specificities since such conditions (for instance, climatic conditions, building envelope thermo-physical and optical properties, heating/cooling systems, cost of energy, intervention costs, etc.) are defined externally, e.g., within a building energy simulation tool producing buildings' KPIs or received by available technical studies or EPCs. Finally, the KPIs' processor PLUG-IN is again independent of regional specificities since it only serves for the ranking of the foreseen projects based on a common MCA algorithm. The generalized character and replicability potential of the IMPULSE tools have also been addressed in previous studies and projects [10,24,26].

As far as the Greek context is concerned, the methodology is enriched, including explanations on how to exploit the IMPULSE tools for addressing the official ministerial guidelines for the development of regional or municipal public buildings' energy efficiency plans. In the form of a simple flow diagram, the information exchange between the IMPULSE tools and the ministerial planning-report template is adequately presented in Figure 1.

Based on the typology approach, the 10 priority buildings of the case study are classified into four public building typologies (PBTs), for each one of which an ambassador building is selected. Taking advantage of the ability of the KPIs' processor in projecting KPIs from each ambassador to the rest of the buildings of the same typology, energy analysis was required only for the four ambassador buildings. This is externally performed, as explained in Section 3.2. Reviewing the results in Tables 6–9 the following are concluded:

- For all ambassador buildings, thermal-protection envelope interventions envisaged in the medium retrofit scenario present the highest payback period. Especially for the two school buildings, and despite the relatively high primary-energy saving (around 20%), the investment is prohibitive because of extremely long payback periods (over 50 years).
- Investment attractiveness is improved by moving toward the major and deep retrofit levels. For the latter, which includes RES integration, primary-energy saving reaches around 93% with analogous CO_2 emissions avoidance and energy cost reduction. In terms of payback period, it is estimated at around 10 years, ranging between 20 and 30 years for the office and school buildings, respectively. Less attractiveness occurs for the school buildings because of the periods of no operation for about 4 months of holidays per year.

Using the KPIs' processor, the KPIs are extrapolated from each ambassador building to the rest of the buildings of each typology. Consequently, the tool provided a database of KPIs in the base case and for the three retrofit levels. As shown in Figure 6 and in Table 10, the payback period is significantly reduced in the deep retrofit scenario. Deep retrofitting of all buildings would lead to primary energy savings of more than 1850 MWh and CO_2 emissions avoidance of around 412 tns, within a total investment of approx. EUR 3 million. To develop a gradual renovation plan until the deep retrofit of all buildings, the multi-criteria assessment PLUGIN tool is used. The decision-making scheme is concluded through practicing alternative combinations of decision-criteria weights. The latter are finalized when most of the goals set by the municipal authority are met. Finally, a 6-year gradual renovation road map is concluded (refer to Figure 9), which ensures a similar number of projects per year, acceptable investment and high energy, environmental and economic benefits. Interestingly, although the MCA scheme defined in Figure 8 is biased toward the investment cost parameter, as shown in Figure 10, the investment in the first year of implementation is the highest. This is because the PLUGIN tool initially ranks the projects primarily based on their estimated total investment and then produces the projects' "veil" based on the imposed floor-area-based renovation rate. This means that although in the first year of implementation, the highest investment emerges, this refers to projects of less investment cost individually (medium and major retrofits). However, due to the imposed renovation rate, enough lower-cost projects are fitted in the floor-area-renovated condition, so they are indeed allocated in the first year accompanied with the sum of the foreseen lower-cost investments. Obviously, in the, case studied and for the specific MCA inputs, the latter happened to become higher than in the following years in which, although higher investments (deep retrofits) emerged, the presented investment is only the remaining part of the deep retrofit having its major-retrofit part excluded from the sum, as already foreseen in the previous year.

Concerning the limitations of the work, first of all, the proposed methodology is based on the correct clustering of the building stock. Scientifically speaking, this means that every detail that affects energy performance should be taken into account, and the clustering would have the highest discretization capacity possible. However, the scope of this work was to demonstrate the exploitation of the selected tools rather than the external processing required to use the selected tools. Nevertheless, the classification criteria adopted herein are still considered reliable for practical planning purposes. Regarding the fidelity of the produced KPI database, this is mainly dependent again on the external sources providing the KPIs. Actual data (e.g., measurements) would be the ideal source, or alternatively, building energy calculations could be used. The latter refers to the case studied herein, i.e., the KPIs are taken from calculations obtained by the national energy calculation methodology. At least regarding the ambassadors' base-case situation, similar energy performance indicators are found in the extensive study in ref. [40] for similar buildings. Finally, regarding the practicability of the selected set of tools, it should be mentioned that the IMPULSE tools are limited to a building stock of up to 90 buildings and up to 15 building typologies.

The following are suggested as future work activities:

- Improve buildings' clustering through including additional important classification criteria and ranges toward increasing the fidelity of planning predictions;
- Focus more on the validation of the methodology through using more advanced energy simulation tools, as suggested, for example, in ref. [10], and comparisons with actual data (e.g., energy measurements).

5. Conclusions

In view of meeting the key challenges regarding the acceleration of renovation rates of the EU public building stock specifically at the local level from the side of regions and municipalities, this paper introduced a concrete stepwise methodology to support the latter authorities to set up reliable and affordable public building energy efficiency plans. The methodology is comprised of practical and easy-to-use tools already tested in the wider Mediterranean region, specifically those introduced by Mediterranean cooperation projects. Following a targeted evaluation procedure, the paper reports the capabilities of each tool with respect to the key pillars of energy efficiency planning. The IMPULSE project set of tools is exploited through a planning-methodology development and testing to a Greek case study. The following conclusions are drawn:

- Generally, the presented methodology is considered practical and fits well within the requirements for building an energy renovation plan in relation to EU and national policies and regulations.
- The methodology is flexible, specifically in terms of the development of the renovation road map, since due to the PLUG-IN tool, alternative road maps may be produced very fast just by altering the multi-criteria assessment scheme inputs.
- Provided that at least the most important energy-influencing technical parameters are adopted for buildings' clustering purposes, the suggested approach significantly

accelerates the production of the renovation plan since detailed energy analyses are required only for the typologies' representative buildings (ambassadors) rather than for all buildings of the building stock.

- The main limitations of the methodology are related to the procedures for concluding the building typologies and ambassadors, as well as for retrieving the latter's KPIs for the base case and the various retrofit scenarios. Therefore, verification activities are strongly recommended, e.g., through comparisons of simulated data with available measurements or at least with the energy performance of similar buildings.
- For the case studied, the methodology provided a feasible 6-year renovation plan outlining the specific buildings and projects to be implemented each year. Informative indicators associate the road map—i.e., absolute and cumulative energy savings, energy-cost savings, emissions avoidance and investment cost—which facilitates the determination of a specific energy efficiency goal to be achieved in the following years in accordance to other possible plans or commitments, e.g., the Sustainable Energy and Climate Action Plan (SECAP).
- Based on the splitting of the required investment produced by the plan, the interested authority can easily and effectively attract the attention of specific funding programs and adjust the preparations of technical energy-upgrading proposals for submission.

It may be concluded that the proposed methodology is useful, particularly for the planners involved in the development of strategic plans and operational programs focused on the energy efficiency of the public building stock on behalf of local authorities because of its ease of use and identified flexibilities. It may also be helpful for technicians involved in conducting technical studies of buildings based on the produced renovation road map. From the strategic point of view, the results obtained by the methodology facilitate decision and policy makers to formulate the renovation agenda, taking into account the foreseen impacts regarding the techno-economic performance of the suggested projects.

Author Contributions: Conceptualization, G.M.S. and P.L.Z.; methodology, G.M.S.; software, P.L.; validation, K.T., P.S. and Y.J.S.; formal analysis, G.M.S.; investigation, G.M.S.; resources, P.S.; data curation, P.L.; writing—original draft preparation, G.M.S.; writing—review and editing, G.M.S. and P.L.Z.; visualization, P.L.; supervision, Y.J.S.; project administration, P.S. and K.T.; funding acquisition, Y.J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the ENI CBC Mediterranean Sea Basin Programme in the framework of the project SEACAP 4 SDG, grant number C_B.4.3_0058.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors wish to thank Chrysoula Christia from the Municipality of Aigialeia for providing all the necessary information, data and documentation for the implementation of the case study activities.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The main contents and exploitation procedures of the selected tools are described as follows:

Tool-1/PBT-Library: worksheets and procedure of use:

- First, in the last worksheet "Dropdown menus" values and ranges of each classification criteria (building use, period of construction, number of floors, heating/cooling systems, etc.) are inserted depending on the building stock recorded and key national (or local) regulations related to energy efficiency (for example, the building use defines the operational schedule of the building, thus the energy consumption; hence, the different building types recorded in the stock should be enlisted in the related input in the tool).

- In the worksheet "List of PB & CC_Absolute values", for each building, the absolute value of each classification criterion is inserted toward formulating the catalogue of the buildings accompanied with their technical characteristics.
- The worksheet "List of Public Buildings & PBTs" is used to redefine the building stock in terms of replacing the absolute value of each classification criterion by the corresponding range from a drop-down list of the available options created in the worksheet "Dropdown menus". Finally, buildings with the same classification ranges of each criterion are allocated to the same PBT, hence formulating the final list of public buildings classified into typologies.
- Finally, 15 worksheets named "Details for Ambassador of PBT" are available to insert technical details for up to 15 representative buildings of the identified typologies. Each representative building stands for an ambassador of the respective typology, reflecting the energy performance of all buildings of the typology. It is strongly recommended to choose ambassadors with the maximum available technical information (structure, systems properties, etc.) and/or available energy studies or EPCs if they exist.

Tool-2/KPIs' processor: worksheets and procedure of use:

- According to the tool instructions, it is recommended to start with the worksheet "Projection_base-case". The name, floor area and the corresponding no. of PBT are inserted for each building of the considered stock.
- For the various states of each PBT's ambassador building, i.e., base case, minor retrofit, medium retrofit, major retrofit and deep retrofit, the energy, environmental (emissions) and cost indicators are inserted in each corresponding worksheet. This means that the state KPIs, e.g., energy consumption per end-use and per carrier, CO_2 emissions and energy consumption cost, should be available for the various building conditions (base case and various levels of retrofit), e.g., obtained by energy simulations or received from available studies or EPCs.
- Finally, based on the assumption that buildings of the same typology share the same normalized values per sq.m. of floor area of the KPIs, in the "Projection" worksheets, the state and impact KPIs are extrapolated from each ambassador to each building of the same typology. Hence, the tool produces a KPI database for all buildings and for all retrofit scenarios considered.
- An intermediate worksheet "Prioritization" is also available that automatically provides a hierarchy of retrofit scenarios for each PBT based on the combined indicator, "Total investment cost per total annual energy saved".

Tool-3/KPIs-processor's PLUGIN: worksheets and procedure of use:

- Inputs are provided in the worksheet "MCA-INPUT" as follows: (a) initially, up to five KPIs are selected as decision-making criteria from the list of KPIs originating in the KPIs' processor—in parallel, a weight factor for each criterion is inserted; (b) optionally, the user can bias the decision to a certain PBT, retrofit level or RES integration; (c) the desired renovation rate in terms of annual % of floor area retrofitted is imposed; (d) the options of buildings and levels of retrofit to be ranked are defined in a matrix enlisting all PBTs and a binary 1 (YES)–0 (NO) input definition for each level of retrofit, declaring whether the scenario is considered in the ranking or not, respectively.
- The tool automatically provides the suggested retrofitting road map in the worksheet "PLAN".
- It should be highlighted that the tool is functional if and only if it exists in the same electronic folder with the previous completed "KPIs' processor" and that both Excel files are open while processing.

Appendix B

The sensitivity analysis for the different sets of combinations of the weights imposed in the "KPIs' processor PLUGIN" tool, corresponding to the selected decision-making criteria, is presented in Table A1.

Table A1. Alternative renovation plans produced for the different sets of weights of the decision-making criteria.

		Weights Combination 1 (Comb1)	Total Annual Primary Energy Savings (DC1)	Total Annual Avoided CO_2 Emissions (DC2)	Investment Cost (DC3)		
			30%	10%	60%		
Years of implementation		1	2	3	4	5	6
Annual absolute	Floor area retrofitted m^2	6942.00	4580.00	980.00	2070.00	1870.00	1115.00
	Annual investment EUR	1,162,994.08	739,936.46	289,431.86	331,751.40	302,272.70	236,289.18
	Cost savings EUR/yr	59,757.49	39,869.42	29,236.35	18,350.67	15,142.61	9274.82
	Avoided CO_2 tns/yr	141.48	95.66	71.83	45.33	36.04	22.05
	Energy savings kWh/yr	640,781.73	435,284.01	329,561.31	208,339.27	163,550.20	100,037.80
Annual accumulated	Floor area retrofitted m^2	6942.00	11,522.00	12,502.00	14,572.00	16,442.00	17,557.00
	Investment EUR	1,162,994.08	1,902,930.55	2,192,362.41	2,524,113.81	2,826,386.51	3,062,675.69
	Cost savings EUR/yr	59,757.49	99,626.92	128,863.26	147,213.93	162,356.54	171,631.35
	Avoided CO_2 tns/yr	141.48	237.13	308.96	354.29	390.33	412.39
	Energy savings kWh/yr	640,781.73	1,076,065.74	1,405,627.05	1,613,966.32	1,777,516.52	1,877,554.32
PROJECTS PER YEAR		PBT2–Municipal office of Aigeira–Medium Retrofit PBT2–Municipal office of Aigeira–Major Retrofit PBT2–Municipal office of Akrata–Medium Retrofit PBT1–1st professional high school of Aigio–Deep retrofit	PBT2–Municipal office of Aigeira–Deep retrofit PBT2–Municipal office of Akrata–Major Retrofit PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Akrata–Deep retrofit PBT2–Municipal office of Sympoliteia–Deep retrofit PBT3–Municipal office of Diakopto–Major Retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT1–1st junior high school of Aigio–Deep retrofit	PBT1–1st Elem. school of Aigio–Major Retrofit PBT1–1st Elementary school of Aigio–Deep retrofit PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT4–Junior high school of Akrata–Deep retrofit
% primary energy saving (cumulative)		32.37%	54.36%	71.01%	81.54%	89.80%	94.86%
		Weights Combination 2 (Comb2)	Total Annual Primary Energy Savings (DC1) 10%	Total Annual Avoided CO_2 Emissions (DC2) 30%	Investment Cost (DC3) 60%		
Years of implementation		1	2	3	4	5	6
Annual absolute	Floor area retrofitted m^2	6942.00	4580.00	980.00	2070.00	1870.00	1115.00
	Annual investment EUR	1,162,994.08	739,936.46	289,431.86	331,751.40	302,272.70	236,289.18
	Cost savings EUR/yr	59,757.49	39,869.42	29,236.35	183,50.67	15,142.61	9274.82
	Avoided CO_2 tns/yr	141.48	95.66	71.83	45.33	36.04	22.05
	Energy savings kWh/yr	640,781.73	435,284.01	329,561.31	208,339.27	163,550.20	100,037.80
Annual accumulated	Floor area retrofitted m^2	6942.00	11,522.00	12,502.00	14,572.00	16,442.00	17,557.00
	Investment EUR	1,162,994.08	1,902,930.55	2,192,362.41	2,524,113.81	2,826,386.51	3,062,675.69
	Cost savings EUR/yr	59,757.49	99,626.92	128,863.26	147,213.93	162,356.54	171,631.35
	Avoided CO_2 tns/yr	141.48	237.13	308.96	354.29	390.33	412.39
	Energy savings kWh/yr	640,781.73	1,076,065.74	1,405,627.05	1,613,966.32	1,777,516.52	1,877,554.32

Table A1. *Cont.*

PROJECTS PER YEAR		PBT2–Municipal office of Aigeira–Medium Retrofit PBT2–Municipal office of Aigeira–Major Retrofit PBT2–Municipal office of Akrata–Medium Retrofit PBT1–1st professional high school of Aigio–Deep retrofit	PBT2–Municipal office of Aigeira–Deep retrofit PBT2–Municipal office of Akrata–Major Retrofit PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Akrata–Deep retrofit PBT2–Municipal office of Sympoliteia–Deep retrofit PBT3–Municipal office of Diakopto–Major Retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT1–1st junior high school of Aigio–Deep retrofit	PBT1–1st Elementary school of Aigio–Major Retrofit PBT1–1st Elementary school of Aigio–Deep retrofit PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT4–Junior high school of Akrata–Deep retrofit	
% primary energy saving (cumulative)		32.37%	54.36%	71.01%	81.54%	89.80%	94.86%	
		Weights Combination 3 (Comb3)	**Total Annual Primary Energy Savings (DC1) 60%**	**Total Annual Avoided CO_2 Emissions (DC2) 10%**	**Investment Cost (DC3) 30%**			
Years of implementation		1	2	3	4	5	6	7
Annual absolute	Floor area retrofitted m^2	6832.00	4450.00	900.00	1850.00	1640.00	1115.00	770.00
	Annual investment EUR	1,104,346.05	719,312.05	264,912.81	299,039.84	314,310.53	236,289.18	124,465.23
	Cost savings EUR/yr	55,323.15	36,034.55	27,601.25	14,980.65	22,181.75	9274.82	6235.19
	Avoided CO_2 tns/yr	131.68	85.77	67.32	35.66	55.08	22.05	14.84
	Energy savings kWh/yr	597,526.72	389,197.00	308,066.02	161,801.00	253,581.58	100,037.80	67,344.20
Annual accumulated	Floor area retrofitted m^2	6832.00	11,282.00	12,182.00	14,032.00	15,672.00	16,787.00	17,557.00
	Investment EUR	1,104,346.05	1,823,658.09	2,088,570.91	2,387,610.75	2,701,921.28	2,938,210.46	3,062,675.69
	Cost savings EUR/yr	55,323.15	91,357.70	118,958.95	133,939.60	156,121.35	165,396.16	171,631.35
	Avoided CO_2 tns/yr	131.68	217.45	284.76	320.42	375.49	39.55	412.39
	Energy savings kWh/yr	597,526.72	986,723.72	1,294,789.74	1,456,590.74	1,710,172.32	1,810,210.12	1,877,554.32
PROJECTS PER YEAR		PBT1–1st professional high school of Aigio–Deep retrofit	PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Aigeira–Medium Retrofit PBT2–Municipal office of Sympoliteia–Deep retrofit PBT2–Municipal office of Aigeira–Major Retrofit PBT2–Municipal office of Akrata–Medium Retrofit PBT2–Municipal office of Aigeira–Deep retrofit PBT2–Municipal office of Akrata–Major Retrofit	PBT1–1st junior high school of Aigio–Deep retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT2–Municipal office of Akrata–Deep retrofit PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT4–Junior high school of Akrata–Deep retrofit	PBT1–1st Elementary school of Aigio–Deep retrofit
% primary energy saving (cumulative)		30.19%	49.85%	65.41%	73.59%	86.40%	91.45%	94.86%
		Weights Combination 4 (Comb4)	**Total Annual Primary Energy Savings (DC1) 10%**	**Total Annual Avoided CO_2 Emissions (DC2) 60%**	**Investment Cost (DC3) 30%**			
Years of implementation		1	2	3	4	5	6	7

Table A1. *Cont.*

Annual absolute	Floor area retrofitted m^2	6832.00	4450.00	900.00	1850.00	1640.00	1115.00	770.00
	Annual investment EUR	1,104,346.05	719,312.05	264,912.81	299,039.84	314,310.53	236,289.18	124,465.23
	Cost savings EUR/yr	55,323.15	36,034.55	27,601.25	14,980.65	22,181.75	9274.82	6235.19
	Avoided CO_2 tns/yr	131.68	85.77	67.32	35.66	55.08	22.05	14.84
	Energy savings kWh/yr	597,526.72	389,197.00	308,066.02	161,801.00	253,581.58	100,037.80	67,344.20
Annual accumulated	Floor area retrofitted m^2	6832.00	11,282.00	12,182.00	14,032.00	15,672.00	16,787.00	17,557.00
	Investment EUR	1,104,346.05	1,823,658.09	2,088,570.91	2,387,610.75	2,701,921.28	2,938,210.46	3,062,675.69
	Cost savings EUR/yr	553,23.15	91,357.70	118,958.95	133,939.60	156,121.35	165,396.16	171,631.35
	Avoided CO_2 tns/yr	131.68	217.45	284.76	320.42	375.49	39.55	412.39
	Energy savings kWh/yr	597,526.72	986,723.72	1,294,789.74	1,456,590.74	1,710,172.32	1,810,210.12	1,877,554.32
PROJECTS PER YEAR		PBT1–1st professional high school of Aigio–Deep retrofit	PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Aigeira–Medium Retrofit PBT2–Municipal office of Sympoliteia–Deep retrofit PBT2–Municipal office of Aigeira–Major Retrofit PBT2–Municipal office of Akrata–Medium Retrofit PBT2–Municipal office of Aigeira–Deep retrofit PBT2–Municipal office of Akrata–Major Retrofit	PBT1–1st junior high school of Aigio–Deep retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT2–Municipal office of Akrata–Deep retrofit PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT4–Junior high school of Akrata–Deep retrofit	PBT1–1st Elementary school of Aigio–Deep retrofit
% primary energy saving (cumulative)		30.19%	49.85%	65.41%	73.59%	86.40%	91.45%	94.86%
		Weights Combination 5 (Comb5)	**Total Annual Primary Energy Savings (DC1) 30%**	**Total Annual Avoided CO_2 Emissions (DC2) 60%**	**Investment Cost (DC3) 10%**			
Years of implementation		1	2	3	4	5	6	
Annual absolute	Floor area retrofitted m^2	6832.00	4450.00	2510.00	1555.00	1100.00	1110.00	
	Annual investment EUR	1,104,346.05	719,312.05	484,680.20	356,431.78	177,807.47	220,098.14	
	Cost savings EUR/yr	55,323.15	36,034.55	34,312.68	20,859.44	8907.42	16,194.11	
	Avoided CO_2 tns/yr	131.68	85.77	83.29	51.08	21.20	39.38	
	Energy savings kWh/yr	597,526.72	389,197.00	380,525.00	234,079.40	96,206.00	180,020.20	
Annual accumulated	Floor area retrofitted m^2	6832.00	11,282.00	13,792.00	15,347.00	16,447.00	17,557.00	
	Investment EUR	1,104,346.05	1,823,658.09	2,308,338.30	2,664,770.08	2,842,577.55	3,062,675.69	
	Cost savings EUR/yr	55,323.15	91,357.70	125,670.38	146,529.82	155,437.24	171,631.35	
	Avoided CO_2 tns/yr	131.68	217.45	300.73	351.81	373.01	412.39	
	Energy savings kWh/yr	597,526.72	986,723.72	1,367,248.72	1,601,328.12	1,697,534.12	1,877,554.32	
PROJECTS PER YEAR		PBT1–1st professional high school of Aigio–Deep retrofit	PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Sympoliteia–Deep retrofit PBT1–1st junior high school of Aigio–Deep retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT4–Junior high school of Akrata–Deep retrofit	PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT2–Municipal office of Akrata–Deep retrofit PBT2–Municipal office of Aigeira–Deep retrofit PBT1–1st Elementary school of Aigio–Deep retrofit	

Table A1. *Cont.*

% primary energy saving (cumulative)		30.19%	49.85%	69.07%	80.90%	85.76%	94.86%
		Weights Combination 6 (Comb6)	**Total Annual Primary Energy Savings (DC1) 60%**	**Total Annual Avoided CO_2 Emissions (DC2) 30%**	**Investment Cost (DC3) 10%**		
Years of implementation		1	2	3	4	5	6
Annual absolute	Floor area retrofitted m^2	6832.00	4450.00	2510.00	1555.00	1100.00	1110.00
	Annual investment EUR	1,104,346.05	719,312.05	484,680.20	356,431.78	177,807.47	220,098.14
	Cost savings EUR/yr	55,323.15	36,034.55	34,312.68	20,859.44	8907.42	16,194.11
	Avoided CO_2 tns/yr	131.68	85.77	83.29	51.08	21.20	39.38
	Energy savings kWh/yr	597,526.72	389,197.00	380,525.00	234,079.40	96,206.00	180,020.20
Annual accumulated	Floor area retrofitted m^2	6832.00	11,282.00	13,792.00	15,347.00	16,447.00	17,557.00
	Investment EUR	1,104,346.05	1,823,658.09	2,308,338.30	2,664770.08	2,842577.55	3,062,675.69
	Cost savings EUR/yr	55,323.15	91,357.70	125,670.38	146,529.82	155,437.24	171,631.35
	Avoided CO_2 tns/yr	131.68	217.45	300.73	351.81	373.01	412.39
	Energy savings kWh/yr	597,526.72	986,723.72	1,367,248.72	1,601,328.12	1,697,534.12	1,877,554.32
PROJECTS PER YEAR		PBT1–1st professional high school of Aigio–Deep retrofit	PBT1–1st senior high school of Aigio–Deep retrofit	PBT2–Municipal office of Sympoliteia–Deep retrofit PBT1–1st junior high school of Aigio–Deep retrofit	PBT3–Municipal office of Diakopto–Deep retrofit PBT4–Junior high school of Akrata–Deep retrofit	PBT1–2nd Elementary school of Aigio–Deep retrofit	PBT2–Municipal office of Akrata–Deep retrofit PBT2–Municipal office of Aigeira–Deep retrofit PBT1–1st Elementary school of Aigio–Deep retrofit
% primary energy saving (cumulative)		30.19%	49.85%	69.07%	80.90%	85.76%	94.86%

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