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D3.5 – REPORT ON THE HOLISTIC IMPACTS ON RENOVATION INTEGRATED SOLUTIONS

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Date	**Change**	**Author**	**Resulting Document Version**
12/07/2021	- Disclaimer updated; - Section 2 updated; - Cross-references typos in Section 2 amended; - The sub-section 2.3 of previous report has been splitted into 2.3: Discussion and 2.4 Conclusions. This last subsection is new	Monica Cariola, Greta Falavigna (IRCRES – CNR)	HAPPEN_D3.5_Report on holistic impacts on renovation integrated solutions_revJune21

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PUBLISHABLE EXECUTIVE SUMMARY

The Happen project is aimed at stimulating the market uptake of deep retrofitting of buildings, with special regard to the Mediterranean area and to the residential built stock, by tackling major bottlenecks. In the Project framework, the definition of different suitable retrofitting options for each reference building into a specific climate and "integrated sets of renovation measures" plays a pivotal role and is developed in the Work Package 3 entitled "Optimal Solutions". The present deliverable D3.5 belongs to this WP3, in particular refers to the Task 3.4, whose title is "Calculation of the holistic impact of the renovation interventions".

In the present deliverable the aim is to demonstrate the holistic impact of HAPPEN, evaluating the spillover effects both for stakeholders of retrofitting and for society more in general, starting from data of the POSs fine-tuned in Task 3.3 for different countries and climate zones. In a complementary manner to T3.3, the present aim is the economic evaluation of the retrofit investment, not only from a financial point of view, but also from the environmental and social one, first through the comparison of the different solutions of retrofitting also from this point of view in order to define, for each Package of Optimal Solutions (POS) identified in the previous deliverables, the environmental and economic sustainable better solution, using combining results from Life Cycle Costing (i.e., LCC) and non-parametric technique (i.e. DDF methodology). Moreover, the positive externalities due to reduction of energy consumption and less CO_2 emissions will be evaluate, also economically, thanks to the data of a survey carried out among the project partners. For each country, a single analysis will be carried out (with the construction of country files) while, for those whose where data resulted to be available, a cross-sectional analyses will be performed, to compare how the various countries behaved in terms of energy efficiency during the three periods considered.

For some countries, using data and results of the DDF methodology and of the survey between the countries, a comparison will be made between before (current state of the stock of building emerging from the survey and related Primary Energy Consumption and CO_2 emissions) and after deep retrofitting, in terms of possible environmental improvements and also economic savings. The main idea is to estimate costs recovery referred to CO_2 and Primary Energy Consumption if the buildings of the pilot cases studies presented in deliverable D3.4 adopted the optimal solutions selected through the holistic efficiency score developed in the present deliverable.

Measures on the energy efficiency of buildings, and consequently actions aimed at promoting retrofitting interventions, are very important because more and more studies are showing that, unlike what was previously thought, i.e. thermal systems for heating buildings have an impact on total CO_2 emissions in urban areas, which is up to 6 times higher than the incidence of vehicular traffic.

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ACRONYMS AND ABBREVIATIONS

DDF	Directional Distance Function
DEA	Data Envelopment Analysis
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MFH	Multifamily House
PBs	Pilot Buildings
PEC	Primary Energy Consumption
POS	Package of Optimal Solutions
RBs	Reference Buildings
RCs	Reference Climates
SFH	Single-family House

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1 INTRODUCTION

There is significant evidence that the world is warming. The International Panel of Climate Change stated that there would be a steady increase in the ambient temperature during the the 21st century. This increase is already impacting the building sector, particularly with reference to the energy requirements for buildings. Many studies discuss issues related to the potential impact of global warming on energy use and these issues could be particularly topical for the building sector in the Mediterranean Countries. Simulation studies and energy analysis were employed to investigate the energy consumption of buildings and the most effective measures to cope with this impact under different climate scenarios. In the case of residential buildings the global warming is likely to increase the energy used for buildings considerably, especially for cooling. Only with reference to this kind of energy use, the net CO_2 emissions could increase up to 5% more over the next few decades [1].

In the last few years, several milestones were set for energy efficiency both in Europe and in several countries as regards the construction sector. Among all, the EU Directive 2018/2844 according to which European countries must develop a long-term strategy to support the renovation of residential and non-residential buildings, both public and private, in order to obtain a decarbonised and high efficiency real estate park by 2050, and will have to facilitate the transformation of existing buildings into almost zero energy buildings [2].

In the update of the Energy Performance in Construction Directive (2018/844 / EU - EPBD) for the achievement of the 2030 objectives of the Energy and Climate Union, some important innovations are introduced, including the obligation to improve the energy performance of new and existing buildings and to make long-term property renovation strategies more effective and to encourage the use of information technology in buildings.

The Energy Efficiency Directive (2018/2002 / EU - EED) required Member States to implement measures capable of maximizing the effectiveness of energy efficiency interventions at the lowest possible cost. The 32.5% energy efficiency targets for 2030 (with the possibility of an upward revision in 2023) and the obligation for Member States to obtain new annual energy savings of 0.8% in the 2021-2030 period are introduced. European standards required that national governments develop a draft Integrated National Plan for Energy and Climate, which contains the calculation of the volume of energy savings to be made during the period 2021-2030. The final adoption of the Plan was to take place by December 2019, with subsequent updating every ten years.

In order to achieve the energy efficiency targets set for the 2014-2020 period, Article 7 of the EED Directive (2012/27 / EU) has provided that all Member States introduce a mandatory national energy efficiency regime into their legislation (EEO) and / or alternative policy measures (AM). Most countries (25 out of 28 states) have decided to introduce a combination of mandatory efficiency schemes and alternative measures.

The alternative measures mainly belong to the following categories: Energy or carbon taxes; Financial instruments or tax incentives; Regulations or voluntary agreements; Standards and norms.

Most of the alternative measures proposed by the Member States, more than 40%, have been of a financial nature, mainly in the form of grant schemes and low interest loans. Taxes on energy and CO_2 are less popular and form part of the package of measures introduced in only 8 Member States. However, they are expected to contribute 14% to the expected energy savings.

The following table 1.1 summarizes in percentage terms the contribution provided by the measures dedicated to building on the total energy saving target that each country has set itself to achieve by 2020.

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COUNTRY	% OF ENERGY SAVING
Spain	34,26%
France	0,71%
Italy	34,58%
Slovenia	81,38%
Croatia	0,03%
Greece	16,35%
Cyprus	3,03%

Source: Enea 2019

Tab 1.1 Final energy saving target (%) to 2020 obtained by the Happen Countries with the application of the main alternative measures dedicated to building

We can see how Slovenia is the one with the highest target, 81,38%, (thanks to ECO Fund program), while Croatia and France have the lowest target, less than 1%, because they have preferred not to use, if not minimally, alternative energy saving measures for the building.

Measures on the energy efficiency of buildings are very important because more and more studies are showing that, unlike what was previously thought, thermal systems for heating buildings have an impact on total CO_2 emissions in urban areas which is up to 6 times higher than the incidence of vehicular traffic. One important example is a study by the Politecnico di Milano on the impact on urban air quality by the main sources of pollution. It was carried out in 2017 on a representative sample of five medium and large Italian cities of different climatic zones (Milan, Genoa , Florence, Parma and Perugia). This study shows that the contribution of the building heating sector to air pollution in terms of CO_2 emissions is on average equal to 64.2% of the total estimated emissions for the cities considered (from a maximum for Florence and Milan with 75 and 74%, to a minimum of 47% for Genoa, with Parma and Perugia staying in the middle (63 and 63%), compared to 10.2% on average which comes from the sector of mobility and motorized transport. The remaining CO_2 share (25.6%) is instead generated by the industrial activities sector.

For this reason, to improve the air quality in our cities today it is necessary to focus attention not only on the concept of sustainable mobility, but also on that of sustainable heating, adopting energy requalification interventions such as those proposed by the Happen project. Instead in public opinion and in the political-institutional debate, the issue of air pollution and CO_2 in cities is still mainly associated with the sector of mobility and motorized transport.

Also for these reasons, in this task 3.4 of the Happen project, we will try to evaluate what is the global impact of CO_2 deriving from buildings in the Project countries, and what savings could be obtained thanks to the proposed retrofitting activities, if applied to all the stock of existing buildings.

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1.1 Aims and objectives

The present deliverable refers to the last task (the 3.4) of the WP 3 Optimal solutions (*Definition of an extensive set of cost-optimal packages of solutions to be applied to refurbish the existing building stock with reference to the different target building typologies*) and concerns, after a deep analysis of the building renovation measures to be applied in different typologies of buildings and different climate zones, the "Calculation of the holistic impact of the renovation interventions".

In particular, in task 3.1 the identification of representative climates and reference buildings in Med countries was carried on, through the definition of two basic peculiarities of the Mediterranean Region: the climate conditions (deliverable D3.1) and the reference building/s typologies classes in Med Countries, through a deep analysis of the existing building stock and the tuning of a specific Catalogue (D 3.2).

Then in task 3.2 "Identification of integrated renovation measures", the different suitable retrofitting options were proposed for each reference building into a specific climate and "integrated sets of renovation measures" were identified. In the deliverable D3.3 (Abacus of "renovation measures" at building and district scale) a comprehensive description of the building renovation measures to be applied in each field was depicted. The single measures were then grouped in Packages of Optimal Solutions (POS) in order to be more effective. A solution is a combination of a certain number of renovation measures, one for each field considered. Also, this combination has then to be optimized in terms of the Life Cycle Cost (LCC), initial investment or Payback Period.

In the task 3.3 (deliverable 3.4) the methodology for the determination of a defined number of packages of renovation measures was explained. For each "integrated sets of renovation measures" the needed investment (installation, maintenance) and expected impact on energy savings (kWh/m^{2}year) and CO_2 savings were calculated on reference buildings, taking also into account the reference climate identified into T3.1.

In the present Task 3.4 (D3.5) the aim is to demonstrate the holistic impact of HAPPEN, evaluating the spillover effects both for stakeholders of retrofitting and for society more in general, starting from data of the POS fine-tuned in Task 3.3 for different countries and climate zones. The present aim is an evaluation of the retrofit investment, not only from a financial point of view as in Task 3.3, but also introducing some environmental costs (i.e. CO_2 emissions) in the comparison among the different solutions of retrofitting. This should help to define, for each POS, the environmental and economic sustainable better solution, using combining results from Life Cycle Costing (i.e., LCC) and non-parametric technique. Moreover, we will try to evaluate the positive externalities due to reduction of energy consumption and less CO_2 emissions if the buildings of the pilot cases studies presented in deliverable D3.4 adopted the optimal solutions selected through the holistic efficiency score developed in the present deliverable.

1.2 Relations to other documents

1.2.1 Legal Framework

The Consortium and Project activities are regulated under the following legal framework:

- The Grant Agreement (GA) - contract between the Commission and the Consortium, especially relevant Annex 1 (also known as Description of Action - DoA);
- The Consortium Agreement (CA) - agreement among the Consortium members.

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1.2.2 Other Project Documents

This deliverable is related to the following documents:

WP (3) Title: Optimal Solutions

- D(3).1 Report on representative climates and zoning;
- D(3).2 Catalogue of reference building classes in Mediterranean countries7
- D(3).4 Report on optimal packages of solutions

1.3 Report structure

Starting from the results of task 3.3 (D3.4) and of the POSs identified there, in this task we will try to evaluate some aspects of the more holistic and environmental impact of the use of retrofitting to buildings, from different point of view, considering in particular the savings it allows in terms of CO_2.

CO_2 is not in itself a pollutant, on the contrary it is fundamental for the life of our ecosystems, however its excess in the atmosphere causes an overheating of the climate and, as the empirical evidence is showing and more and more studies on the topic, has very negative consequences on the environment. So a containment of CO_2 emissions is a condition now required by law in most of the sectors and is the basis of the need to increase the energy efficiency of buildings more and more.

In D3.4 among the outputs of the analysis there is also, for each POS identified, the savings levels in terms of CO_2 of each solution contained in the various POSs. Based on this, the present analysis will be conducted along three lines:

1. In a first part (chapter 2), starting from data of POSs of D3.4, a hybrid approach in order to evaluate the environmental and economic sustainability of retrofitting interventions in the Mediterranean climate zones will be proposed. One of the most popular methodologies is the Life Cycle Assessment (i.e., LCA) because it considers not only costs and investment necessary for an intervention but also its spillover on society. For this reason, the LCA can be considered a technique able to contribute to a holistic assessment of retrofitting. However, data required for LCA are not always so easy to find. The aim of the present work is to suggest a hybrid methodology for evaluating different solutions of retrofitting interventions combining results from Life Cycle Costing (i.e., LCC) and non-parametric technique (i.e., Directional Distance Function, DDF). Data envelopment analysis (DEA) techniques, as for instance DDF, are models which allow to consider not only improvements resulting from retrofitting interventions but also the positive environmental impact of the decrease of undesirable outputs, as pollutions or CO_2 emissions. Consequently this kind of analysis permits to evaluate within each POS, which is the best solution not only in economic terms but also, and at the same time, environmental.
2. In the second part (chapter 3) we will present the results of a survey conducted between the countries of the Happen project to try to understand, for each of them, the stock of existing residential buildings and, for those where the data were available, their energy efficiency trend during the three period considered (before 1980, between 1981 and 2000, after 2001), with the level of CO_2 emissions and of Primary Energy Consumptions (PEM) caused by these stocks in each period. For each country, a single analysis will be carried out (with the construction of country files) while, as not all countries provided data on both PEM and CO_2 emissions, where data will be available, also a cross-sectional analyses among the countries will be performed, to compare how they behaved in terms of energy efficiency during the three periods considered.

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3. Starting from data of Spain, France, Cyprus and Croatia , in D3.4 16 POS were obtained, which are applicable in 15 climates (in all the European countries) and 42 RB. In chapter 4 of the present report these output will be use together with data and results of chapter 2 (i.e., DDF methodology) and chapter 3 (survey between the countries), for a comparison between before (current state of the stock of building emerging from the survey and related PEM and CO_2 emissions) and after retrofitting, in terms of possible environmental improvements and also economic savings, thanks to an economic evaluation of the CO_2 saved. The main idea is to estimate costs recovery referred to CO_2 and Primary Energy Consumption if the pilot cases studies presented in deliverable D3.4 adopted the optimal solution selected through the holistic efficiency score in chapter 2.

2 A HYBRID APPROACH IN ORDER TO EVALUATE THE ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF RETROFITTING INTERVENTIONS IN THE MEDITERRANEAN

In D3.4, for each "integrated sets of renovation measures" the needed investment (installation, maintenance) and expected impact on energy savings (kWh/m$^2\cdot$year) and CO_2 savings have been calculated on reference buildings, taking also into account the reference climate identified into Task 3.1.

The methodology used permitted to obtain the global rehabilitation costs and the primary energy consumption for different packages of renovation measures. The global costs required the calculation on the life cycle costs (LCC) for set of packages and the primary energy consumption required the calculation of energy performance for the same set of packages. The set of measures considered were very extensive and related to façades, roofs, slabs, windows, airtightness, thermal bridges, HVAC and ventilation systems. The main variable to minimize have been the Life Cycle Cost (LCC) in 30 years, considering there the investment costs, and the energy costs.

The optimization has consisted on identifying 12 combinations of renovation measures (POS) minimizing the Life Cycle Cost, for each RB of different climate zones and different Countries. As already highlighted in D3.4, this criterion could be discussed because there are other variable that could be optimized, as the energy consumption, the emissions or directly the investment cost. But in D3.4 it was decided to choose as optimization variable only the LCC because it is commonly accepted that it is the more interesting variable for the inhabitants (while the others are more interesting for the estates or for the environment), when it is requested to evaluate the holistic impact of the retrofitting investment.

Also for these reasons, in the present deliverable (D3.5), starting from data of POS identified in D3.4, a hybrid approach in order to evaluate the holistic impact and the sustainability of retrofitting interventions in the Mediterranean climate zones will be proposed.

One of the most popular methodologies is the Life Cycle Assessment (i.e., LCA) because it considers not only costs and investment necessary for an intervention but also its spillover on society. For this reason, the LCA can be considered a technique able to contribute to a holistic assessment of retrofitting. However, data required for LCA are not always easy to find. The aim of the present work is to suggest a hybrid methodology for evaluating different solutions of retrofitting interventions combining results from Life Cycle Costing (i.e., LCC) and non-parametric technique (i.e., Directional Distance Function, DDF).

The Data Envelopment Analysis (i.e., DEA), as other non-parametrique techniques, evaluate each observation (i.e., in this case, each POS) assigning an efficiency score based on the minimization of necessary ressources needed for the intervention or the maximization of benefits due to retrofitting

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investment. In details, the Directional Distance Function (i.e., DDF) is a generalization of DEA, that allows to consider different types of outputs (i.e., desirable as the energy saving and undesirable as CO2 emissions). The main idea of these models is to build a frontier of efficient observation and to observe the inefficiency considering the radial distance of non-effiicient observation from the frontier. In thi manner, this kind of analysis permits also to evaluate within each POS, which is the best solution not only in economic terms but also, and at the same time, environmental.

Finally, it is usefull to remember that the methodology here presented starts from simulated POS described in the text of the deliverable D3.4. For this reason, the simulations taken into consideration refer to two case-studies for singlefamily house (Croatia and Cyprus) and other two for multifamily house (i.e., France and Spain). In this paragraph, the main goal is to present results deriving from a methodology that can be applied to all simulations made with the software presented in the previous deliverable. Although the POS in D 3.4 are based on buildings with the geometry of Spain, France, Croatia and Cyprus pilots, indeed it could be possible to apply the solutions in other countries, as was demonstrated in D3.4. In the same way the analysis could be extended to other countries also in the present analisys.

2.1 Introduction and short literature review on non-parametric techniques

In recent years, the topic of protection and sustainability in industrial sectors has been even more studied by literature. Indeed, a strong attention has been addressed to the topic of environmental protections and pollution, both in terms of energy savings and emissions.

In this context, the scientific research works in order to define performance measures able to consider both environmental and social impact. The scarce availability of information on the costs, the typologies, and amounts of pollution stimulates researchers to study new techniques, both non-parametric and parametric, dealing with this issue. Starting from contribution by [3] that suggests a hyperbolic efficiency measure with non-linear constraints to standard Data Envelopment methodology (DEA), numerous applications have been studied. [4] studies about 100 environmental applications using DEA linear programming, while [5] analyses strengths and weaknesses of main models. A part of the literature on efficiency introduces undesirable outputs using stochastic frontier ([6], [7], [8]), while the asymmetric treatment of good (i.e., the desirable output, as for instance, the energy saving) and bad (i.e., the undesirable output, as for instance, the emission of pollutants) is more difficult where non-parametric models are applied. [9] and [10] study the Directional Distance Function (DDF) as a model able to modify the direction in which searching for the efficient counterpart of each observation, without changing the definition of technology. Another property of the DDF is the additivity, which makes it possible to adopt a standard linear programming procedure, without assumptions about the functional form of technology.

A first set of applied researches refers to US micro-data on very specific sectors like for instance paper and pulp mills ([11]), glass plants ([12]), public transport firms ([13]), thermal power plants ([14]). Other studies apply non-parametric models on regional data ([15]), world countries ([16]), Chinese provinces ([17]), Italian provinces ([18]) or UK regions ([19]).

Finally, a more recent stream of literature suggests to combine non-parametric technique to well-known Life-Cycle Cost (LCC) or Life-Cycle Assessment ([20]; [21]; [22]) in order to evaluate the sustainability of an industry sector ([23]) or, more in general, of an intervention.

However, the data for the classical Life-Cycle Assessment are not always available. Therefore, in the present study we propose to combine the LCC estimation with a specification of the standard DEA

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model, able to consider undesirable outputs, as, for instance, CO2 emissions. In addition, a bootstrap procedure has been adopted in order to obtain more robust results, as suggested in more recent studies ([24]).

The aim of the analysis presented in this chapter is to apply a hybrid model, based on LCC estimates and Directional Distance Function, in order to identify which retrofitting interventions is the most efficient under a holistic point of view, considering both the environmental and the social impact of retrofitting solution proposed. Present work is based on the output on the POSs presented in the D3.4.

2.2 Methodology and data

2.2.1 Other Project Methodology: biased directional distance function

The Directional Distance Function is a non-parametric technique widely used in the environmental field in order to evaluate the efficiency of facilities based on their emissions. However, literature presents applications of this model to many optimization problems with good performances.

The difference of this technique compared with other non-parametric models is the possibility to consider different type of outputs. Indeed, standard data envelopment analysis (DEA) considers efficient that observation able or to maximize outputs taking equal inputs (output-oriented); or to produce the same output minimizing necessary inputs (input-oriented). However, the standard hypothesis is that the output is a good production. The Directional Distance Function (DDF) is a generalization of the DEA model and allows to consider the dual nature of output following [25]. For this purpose, it has been necessary a redefinition of the production technology taking into consideration not only desirable and but also undesirable (or bad) outputs.

In detail, let the initial vector of $i = 1,2,\ldots,s$ outputs $\mathbf{y} \in \Re^{s}_{++}$, it is divided into good and undesirable output, i.e., $\mathbf{y} = (\mathbf{y}^{d}, \mathbf{y}^{u})$ with $\mathbf{y}^{d} \in \Re^{g}_{++}$ and $\mathbf{y}^{u} \in \Re^{r}_{++}$. The technology is built considering constant returns to scale (CRS) and it is defined as $P_{CRS} = \{(\mathbf{x}, \mathbf{y}^{d}, \mathbf{y}^{u}) \mid \mathbf{x} \geq X\lambda, \mathbf{y}^{d} \leq Y\lambda, \mathbf{y}^{u} = Y\lambda, \lambda \geq \mathbf{0}\}$. Literature is still working on variable returns to scale and the debate is not concluded yet. Until now, the majority of studies with directional distance function application considers constant return to scale ([26]; [4]; [27]; [28]; [3]; [29]).

The DDF considers a pre-assigned direction that corresponds to the output vector, defined as $\mathbf{g}_{y} = (\mathbf{y}^{d}, \mathbf{y}^{u}) \neq \mathbf{0}_{m+s}$. Along this vector, it is possible to observe the projection of the efficiency measure $(\mathbf{x}_{o}, \mathbf{y}^{d}_{o}, \mathbf{y}^{u}_{o})$ solving the following linear programming:

$$
\begin{aligned}
\max_{\beta,\lambda} \quad & \beta \\
& X\lambda \leq \mathbf{x}_{o} \\
& Y^{d}\lambda \geq \mathbf{y}^{d}_{o} + \beta\mathbf{y}^{d}_{o} \\
& Y^{u}\lambda \geq \mathbf{y}^{u}_{o} - \beta\mathbf{y}^{u}_{o} \\
& \max\{\mathbf{y}^{u}_{i}\} \geq \mathbf{y}^{u}_{o} - \beta\mathbf{y}^{u}_{o} \\
\text{subject to:} \quad & \lambda \geq \mathbf{0}
\end{aligned}
$$

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β^*_{CRS} = 0 represents the optimal solution (i.e., the observation is efficient); otherwise (i.e., β^*_{CRS} >0), the observation is non-efficient.

As for standard DEA model, [30] described the axioms that the technology has to satisfy:

P1. $\{0\} \in P(x)$ for all $x \in \Re^N_+$. This means that inactivity (i.e., production equal to 0) is always possible;

P2. $P(x)$ is compact $x \in \Re^N_+$. This axiom highlights that finite inputs can only produce finite outputs;

P3. $P(x) \subseteq P(x')$ if $x' \geq x$. This means that inputs are freely disposable. This property suggests that it is possible to increase or decrease inputs without constraints.

However, two additional axioms are required when DDF is applied. These properties are very important and they are respectively called weak disposability of outputs and null-jointness or byproduct:

P4(WD). $(y,b) \in P(x)$ and $0 \leq \theta \leq 1$ imply $(\theta y, \theta b) \in P(x)$. This axiom implies that a reduction of bad outputs requires a reduction in good outputs ([31]).

P5(NJ). $(y,b) \in P(x)$ and $b = 0$ imply $y = 0$. This axiom means that bad outputs are byproducts of the good outputs. In other words, producing good output requires the production also of bad outputs.

As suggested by [32] and [33] referring to the non-parametric models, bootstrapped scores perform well because the resampling methodology allows to obtain more robust efficiency estimates.

Bootstrapping concerns the replication of n dataset randomly starting from the initial sample and until now it has been applied only in few cases ([34]). The main idea, suggested by [33] was to calculate a bias for correcting the efficiency scores and to be more confident on robustness of results (the so called "biased efficiency scores").

In this work, the procedure followed for the bootstrap computation is that suggested by [35].

Once having calculated the directional distance function scores for each bootstrapped sub-sample, each observation (called in DEA models Decision Making Units, DMUs) will present k efficiency scores (where 1 ≤ k ≤ size of sample * Number of replications).

Aiming at calculating the bias and the confidence intervals for efficiency scores, the [32] and [33] procedure is followed.

In order to simplify the notation, considering the mathematical notation for i = 1, where i is the number of DMU.

Let $\hat{\beta}^*(x,y)$ the efficiency score from the basic directional distance function model and $\hat{\beta}^b(x,y)$ the bootstrapped efficiency scores where b=1,…, B (replications).

The correction term for the efficiency score $\hat{\beta}^*(x,y)$ is found as the difference between the mean of bootstrapped efficiency scores ($\overline{\beta}^B(x,y)$) and the efficiency one:

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$$bias = \frac{\sum_{b=1}^{B} \hat{\beta}^b(x,y)}{B} - \hat{\beta}^*(x,y) = \overline{\beta}^B(x,y) - \hat{\beta}^*(x,y)$$

The measure of efficiency with the correction of bias ($\hat{\beta}^*_B(x,y)$) is done by the difference between the efficiency score and the bias, that can be written as 2 times the efficiency score minus the mean of bootstrapped efficiency measure.

$$\hat{\beta}^*_B(x,y) = \hat{\beta}^*(x,y) \text{-bias=} \hat{\beta}^*(x,y) - \frac{\sum_{b=1}^{B} \hat{\beta}^b(x,y)}{B} + \hat{\beta}^*(x,y) = 2 \cdot \hat{\beta}^*(x,y) - \frac{\sum_{b=1}^{B} \hat{\beta}^b(x,y)}{B}$$

The standard error of the distribution of the corrected scores is calculated in the following manner:

$$s\widehat{e} = \left\{ \frac{1}{B-1} \sum_{b=1}^{B} \left[\hat{\beta}^b(x,y) - \overline{\beta}^B(x,y) \right]^2 \right\}^{1/2}$$

Following [32], the percentile confidence intervals (α=0.05) have to be calculated on the distribution of the bootstrapped efficiency scores subtracting 2 times the bias $\widetilde{\beta}^b(x,y) = \hat{\beta}^b(x,y)$ -2*bias.

2.2.2 Data for efficiency scores

Data for efficiency scores refer to Packages of Optimal Solutions (POS) defined in the Deliverable document 3.4 of HAPPEN project.

The work carried out by the USE institute identified 16 POS starting from pilot case-studies studied in the project. The goal of that specific task was to propose 12 solutions for each POS taking into account 2 typologies of buildings (i.e., 2 single-family house, SFH and 2 multifamily houses, MFH) and 4 different climate zones (i.e., W1S2; W2S2; W2S3; W3S2).

From the deliverable 3.1, four climate zones have been chosen because they cover approximatively the whole Mediterranean area. The classification of the climate zones has been conducted on the base of the Climate Severity Index (CSI) that is a measure of climatic conditions and the W means winter, whereas S corresponds to summer.

Following the D3.4, we decided to consider the pilots from Croatia (HR) and Cyprus (CY) as SFH, whereas we selected the front-runner pilots from France (FR) and Spain (SP) as MFHs.

The following Table (2.1) summarizes the research strategy adopted for calculating efficiency scores. Indeed, 8 frontiers have been built, one for each typology of buildings and climate zone. For instance, considering the single-family house and the climate zone W1S2, 12 solutions from Cyprus and 12 solutions from Croatia have been considered simultaneously and then compared[1].

[1] Description of climate zones can be found in deliverable D3.1; description and data of POS are calculated and presented in deliverables D3.4.

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TYPOLOGY OF BUILDING	CLIMATE ZONES	PILOT STUDIES	PILOT STUDIES	SAMPLE SIZE (NUMBER OF SOLUTIONS)	DDF FRONTIER
SFH	W1S2	CY (POS1)	HR (POS5)	24	1
	W2S2	CY (POS2)	HR (POS6)	24	2
	W2S3	CY (POS3)	HR (POS7)	24	3
	W3S2	CY (POS4)	HR (POS8)	24	4
MFH	W1S2	SP (POS13)	FR (POS9)	24	5
	W2S2	SP (POS14)	FR (POS10)	24	6
	W2S3	SP (POS15)	FR (POS11)	24	7
	W3S2	SP (POS16)	FR (POS12)	24	8

Table 2.1: Strategy design for efficiency score evaluation

The sample size is not high but literature on non –parametric methodology suggests that, using constant return to scale, also a little sample allows to obtain acceptable results. In the seminal paper of [36] an interesting debate on sample size is presented. Author suggests an algorithm base on the input-output space dimension of the model in order to identify the good dimension of the sample.

The input-output space for computing the DDF model has been built with the aim to evaluate which solution is the more efficient considering also CO_2 emissions.

With this intent, two input-output spaces have been considered. The outputs are equal for all formulation: one good output (i.e., the total final energy savings per year) and one bad or undesirable (i.e., CO_2 emissions). In the first model (i.e., model#1) the input is represented by the Life Cycle Costing (LCC) of solution; whereas in a second model (i.e., model#2) the total costs has been considered as input.

The total final energy savings per year (MWh). This is the planned absolute value of the final energy savings per year.

The CO_2 emissions describe the value of the CO_2 production after the implementation of the optimal solution proposed in the corresponding line.

The Life Cycle Costing is a methodology that allows to evaluate costs throughout the entire life cycle of the product (i.e., retrofitting intervention), from production to the disposal phase. In the project this variable has been calculated as the initial investment plus the operational costs in 30 years after implementing the optimal solutions. The total cost represents the total expense to implement the corresponding optimal solution.

Independently from the input, the goal of the DDF is to compute a holistic efficiency score, able to compare different solutions considering together resources necessary for the retrofitting interventions and outputs for the whole society.

The meaning of DDF scores suggests which solution is the more efficient in maximizing the energy saving and minimizing CO_2 emissions, taking equal the LCC (model#1) or the necessary total costs (model#2). Both the input-output space strategies are coherent with the axioms on DDF because CO_2 emissions are strictly linked to the activity of renovations. In this way, the weak disposability and the null-jointness are verified. The combination of LCC and DDF allows to obtain holistic efficiency scores because they identify the total spillovers of the retrofitting interventions in terms of energy savings and emissions. This hybrid approach can be considered as a different way for estimating the Life Cycle Assessment when some necessary data are missing. The scores are very simple to understand but, at the same time, their efficacy is proved in literature, always considering the difficulties due to data collection.

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In both designs, the input-output space is made by 3 variables: 1 input and 2 outputs. [36] suggests that the DEA model estimated under CRS, with an input-output space made by 3 variables and 24 observations (i.e., the size of samples) allows to obtain the same robustness of results that we would have expected with a linear regression run on a sample of 69 observations. In addition, the bootstrap and the following bias correction improve the quality of the estimates.

Summarizing, we have defined two models, different in the input-output space. Each of this model has been run in order to obtain an efficiency frontier for each typology of building (I,e., SFH and MFH) and climate zone. This means that respectively 8 frontiers for model#1 and 8 for model#2 have been built. Clearly, we have built 8 DDF frontier considering total costs and 8 with the LCC estimates. It seems necessary to underline again that different production technologies for each climate zone has been evaluated. Costs but especially the energy consumptions can significantly change among geographical area.

Table 2.2. shows descriptive statistics on all variables used as input-output space[2].

TYPOLOGY OF BUILDING	INPUT/ OUTPUT SPACE	VARIABLES	W1S2	W2S2	W2S3	W3S2
SFH	Input (#1)	LCC (mean value, €/m2)	143.10	178.47	219.18	234.50
	Input (#2)	Total costs (€)	18,158	20,006	21,457	22,336
	Bad output	CO2 emissions (kg/m2)	9.24	12.25	16.15	17.12
	Good output	Total final energy saving per year (MWh)	13.50	21.57	25.45	36.94
MFH	Input (#1)	LCC (mean value, €/m2)	115.64	155.71	189.20	199.21
	Input (#2)	Total costs (€)	32,258	46,631	49,920	51,519
	Bad output	CO2 emissions (kg/m2)	8.81	10.75	14.05	14.97
	Good output	Total final energy saving per year (MWh)	31.69	33.80	41.05	58.94

Table 2.2: Descriptive statistics on input-output space (mean values)

2.3 Results on the best holistic efficiency scores

In present section, results obtained with DDF are presented. It is worth mentioning that, as explained in technical section, the more efficient solution presents a holistic efficiency score close to 0.

Results are showen on the basis of typology of buildings and climate zone in order to identify the more efficient solutions within the group.

2.3.1 Single-family House (SFH): the cases of Cyprus and Croatia

In following (Table 2.3) and figure (Figure 2.1) are reported holistic efficiency scores computed on the 24 solutions of the W1S2 climate zone.

The climate zone W1S2 is the less controversial case to analyse. Both models agree in suggesting the solution 9 as the most efficient. This is an interesting result because the first model can be interpreted

[2] Notice that it is not a problem if variables have different units of measure. Indeed, the linear programming is applied to each observations and then solutions are not optimized all together. For a deeper explanation of technical characteristics of non-parametric techniques see [37].

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as the holistic efficiency score, whereas Model#2 considers a technical evaluation: solution 9 is the best POS of climate zone W1S2. On the contrary, the solution less efficacy in terms of sustainability is the number 1, and this result is confirmed for each frontier.

(CY = Cyprus, POS1 and HR = Croatia, POS5)

SOLUTIONS	MODEL#1		MODEL#2	
	CY	HR	CY	HR
1	0.032	0.160	0.198	0.140
2	0.022	0.159	0.160	0.102
3	0.021	0.155	0.143	0.120
4	0.019	0.155	0.148	0.100
5	0.014	0.157	0.128	0.086
6	0.010	0.155	0.113	0.085
7	*0.000*	0.114	0.177	0.037
8	0.007	0.121	0.117	0.009
9	*0.000*	*0.000*	*0.101*	*0.000*
10	*0.000*	0.101	0.140	0.039
11	0.003	0.110	0.124	0.024
12	*0.000*	0.117	0.128	0.010

Table 2.3: Holistic efficiency and technical-economic scores for SFH and WIS2 climate zone

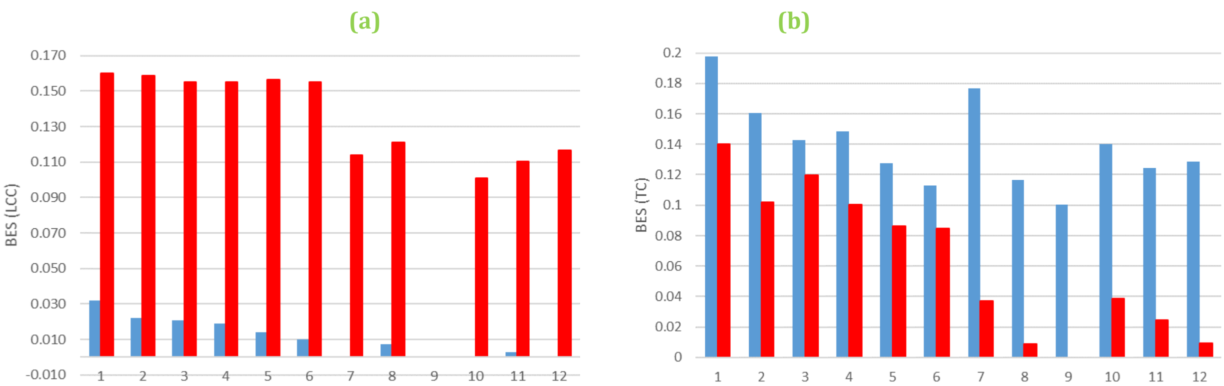

Figure 2.1: Model#1 (a) and Model#2 (b) for Cyprus (blue bars) and Croatia (red bars), W1S2 climate zone

Results concerning the climate zone W2S2 are less univocal (Table 2.4 and Figure 2.2). Model#1 highlights lower holistic efficiency score for the solutions 5 that is more performant also for Cyprus in model#2. Considering the case-study of Croatia, the best solution is the number 1.

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(CY = Cyprus, POS2 and HR = Croatia, POS6)

SOLUTIONS	MODEL#1		MODEL#2	
	CY	HR	CY	HR
1	0.023	0.121	0.031	0.014
2	0.036	0.149	0.121	0.095
3	0.024	0.144	0.113	0.081
4	0.033	0.116	0.165	0.083
5	0.001	0.102	0.014	0.192
6	0.005	0.191	0.037	0.135
7	0.009	0.174	0.040	0.056
8	0.003	0.194	0.021	0.027
9	0.006	0.261	0.087	0.130
10	0.013	0.190	0.097	0.032
11	0.001	0.171	0.089	0.098
12	0.000	0.104	0.140	0.310

Table 2.4: Holistic efficiency and technical-economic scores for SFH and W2S2 climate zone

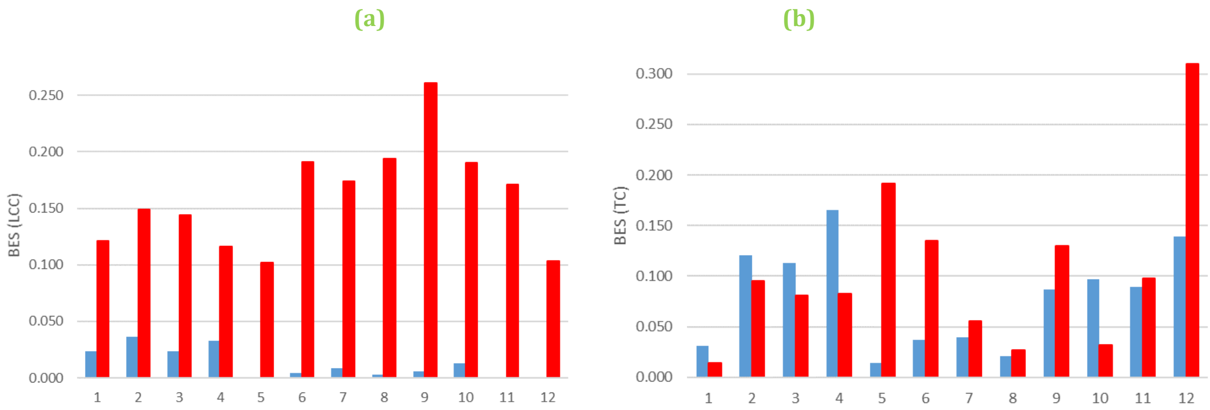

Figure 2.2: Model#1 (a) and Model#2 (b) for Cyprus (blue bars) and Croatia (red bars), W2S2 climate zone

Table 2.5 and Figure 2.3 present results for the third climate zone considered. Model#1 suggests that the more efficient holistic performance is obtained adopting solution number 9. The same result is confirmed by model#2 for Croatia. The situation for Cyprus suggests to adopt solution 2.

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(CY = Cyprus, POS3 and HR = Croatia, POS7)

SOLUTIONS	MODEL#1		MODEL#2	
	CY	HR	CY	HR
1	0.017	0.032	0.045	0.040
2	0.018	0.119	0.024	0.022
3	0.003	0.118	0.134	0.024
4	0.005	0.084	0.153	0.017
5	0.005	0.118	0.061	0.085
6	0.006	0.184	0.058	0.067
7	0.016	0.138	0.149	0.081
8	0.014	0.162	0.235	0.117
9	*0.000*	*0.000*	0.050	0.000
10	0.003	0.133	0.160	0.136
11	0.001	0.140	0.064	0.129
12	0.000	0.136	0.227	0.092

Table 2.5: Holistic efficiency and technical-economic scores for SFH and W2S3 climate zone

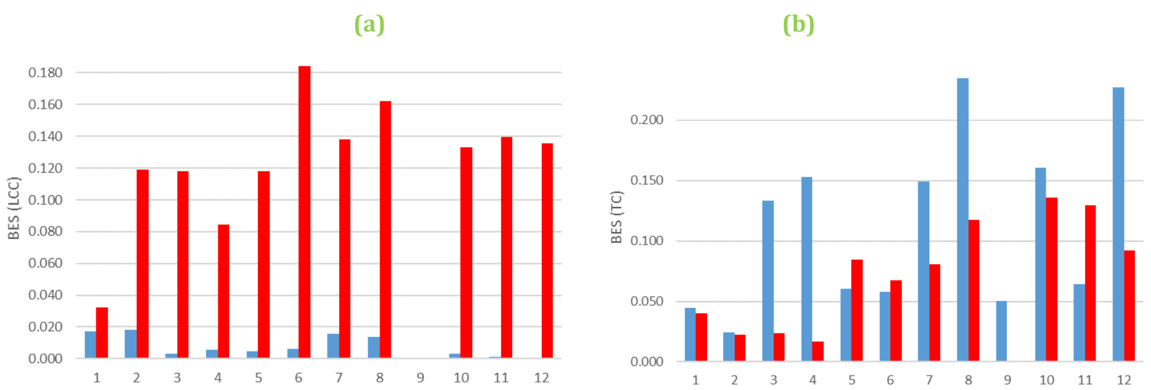

Figure 2.3: Model#1 (a) and Model#2 (b) for Cyprus (blue bars) and Croatia (red bars), W2S3 climate zone

Finally, Table 2.6 and Figure 2.4 represent results of SFH referring to the last climate zone (W3S2). In this case, model#1 suggests to adopt solution 10 or 12 for Cyprus, and 2 for Croatia. Model#2 highlights solution 11 and 12 as more efficient for respectively Cyprus and Croatia.

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(CY = Cyprus, POS4 and HR = Croatia, POS8)

SOLUTIONS	**MODEL#1**		**MODEL#2**	
	CY	**HR**	**CY**	**HR**
1	0.090	0.320	0.076	0.285
2	0.073	0.305	0.257	0.330
3	0.045	0.307	0.093	0.290
4	0.036	0.306	0.000	0.353
5	0.042	0.310	0.069	0.334
6	0.005	0.379	0.263	0.368
7	0.039	0.323	0.093	0.422
8	0.005	0.345	0.215	0.428
9	0.003	0.425	0.070	0.396
10	0.000	0.326	0.131	0.409
11	0.001	0.307	0.015	0.422
12	0.000	0.323	0.029	0.261

Table 2.6: Holistic efficiency and technical-economic scores for SFH and W3S2 climate zone

(a) **(b)**

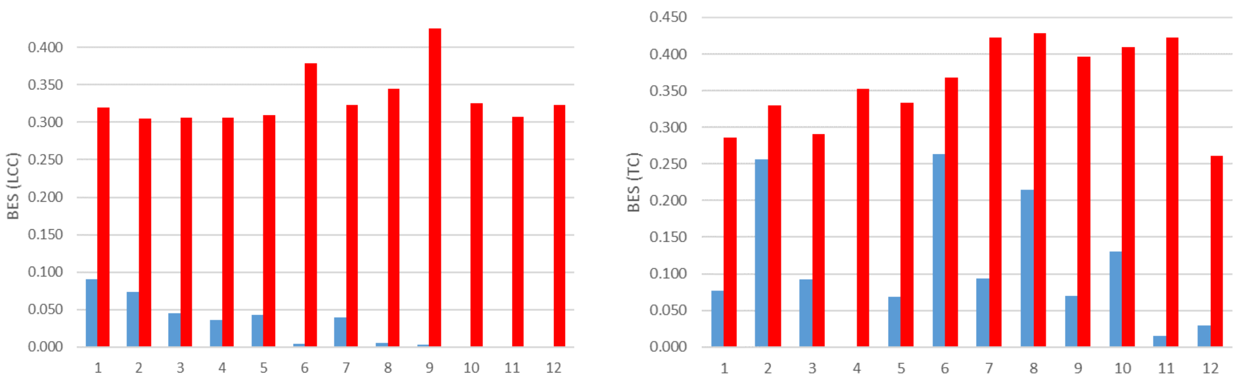

Figure 2.4: Model#1 (a) and Model#2 (b) for Cyprus (blue bars) and Croatia (red bars), W3S2 climate zone

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2.3.2 Multifamily House (MFH): the cases of France and Spain

Two case studies of France and Spain have been evaluated for multifamily houses.

In details, the front-runner pilots, placed in Marseille (France) and in Castellón (Spain). As for single-family houses, the same analysis has been carried on and 8 different frontiers have been built based on climate zones and input-output space.

In the climate zone W1S2 (Table 2.7 and Figure 2.5) results are univocal and suggest, for both models, that holistic efficient frontier is the number 8 and it is interesting to notice that considering LCC as input, there are many optimal solutions in the case of France.

(FR = France, POS13 and SP = Spain, POS9)

SOLUTIONS	MODEL#1		MODEL#2	
	FR	SP	FR	SP
1	0.022	0.242	0.069	0.376
2	0.020	0.151	0.151	0.211
3	0.015	0.132	0.032	0.174
4	0.005	0.122	0.087	0.150
5	0.000	0.089	0.187	0.125
6	0.011	0.074	0.046	0.064
7	0.000	0.045	0.043	0.029
8	0.000	0.000	0.000	0.000
9	0.000	0.095	0.008	0.074
10	0.000	0.060	0.062	0.028
11	0.004	0.141	0.009	0.095
12	0.005	0.132	0.115	0.076

Table 2.7: Holistic efficiency and technical-economic scores for MFH and W1S2 climate zone

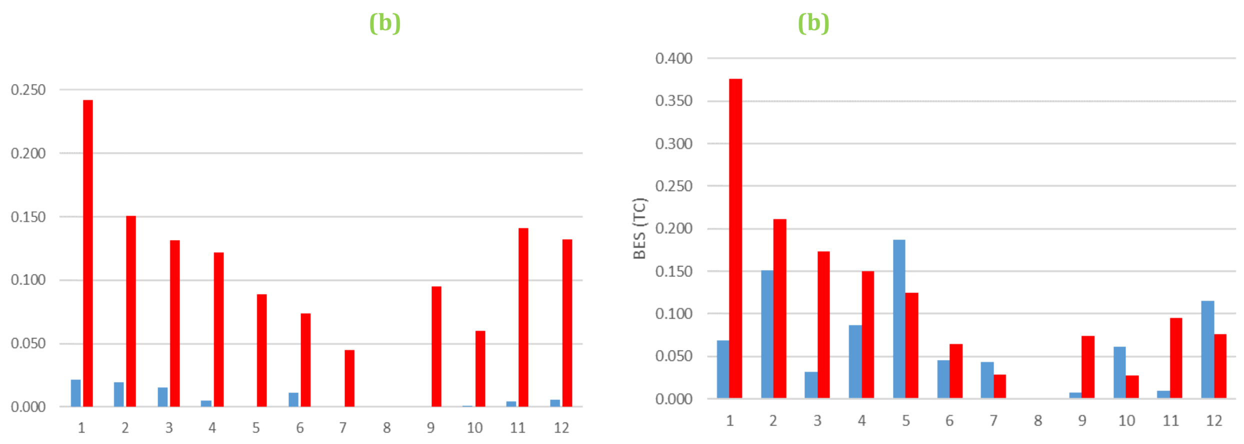

Figure 2.5: Model#1 (a) and Model#2 (b) for France (blue bars) and Spain (red bars), W1S2 climate zone

Results concerning the climate zone W2S2 do not agree (Table 2.8 and Figure 2.6). Indeed, in this case, each model highlights a different efficient solution suggesting a greater variability of the climate zone.

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(FR = France, POS14 and SP = Spain, POS10)

SOLUTIONS	MODEL#1		MODEL#2	
	FR	SP	FR	SP
1	0.013	0.004	0.413	0.776
2	0.022	0.253	0.322	0.143
3	0.018	0.274	0.403	0.197
4	0.018	0.169	0.357	0.062
5	0.009	0.060	0.232	0.243
6	0.004	0.238	0.370	0.012
7	0.017	0.068	0.483	0.277
8	0.021	0.294	0.509	0.000
9	0.000	0.158	0.351	0.086
10	0.000	0.036	0.322	0.301
11	0.011	0.081	0.461	0.078
12	0.004	0.107	0.367	0.059

Table 2.8: Holistic efficiency and technical-economic scores for MFH and W2S2 climate zone

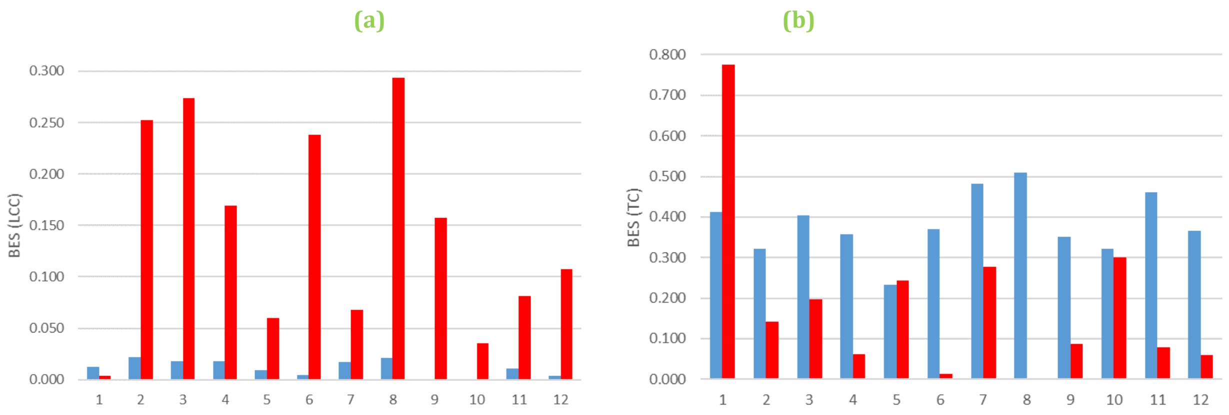

Figure 2.6: Model#1 (a) and Model#2 (b) for France (blue bars) and Spain (red bars), W2S2 climate zone

Similar consideration refers to the climate zone W2S3 (Table 2.9 and Figure 2.7) where for France, model#1 and model#2 are in agreement in suggesting solution 7 as the most efficient, but for Spain, results change considering a different strategy of input-output space.

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(FR = France, POS15 and SP = Spain, POS11)

SOLUTIONS	MODEL#1		MODEL#2	
	FR	SP	FR	SP
1	0.053	0.007	0.552	0.132
2	0.064	0.087	0.498	0.056
3	0.043	0.140	0.535	0.097
4	0.056	0.083	0.511	0.818
5	0.018	0.143	0.305	0.058
6	0.009	0.114	0.455	0.023
7	0.000	0.094	0.033	0.047
8	0.023	0.136	0.505	0.000
9	0.000	0.072	0.445	0.055
10	0.006	0.092	0.410	0.074
11	0.021	0.019	0.507	0.049
12	0.029	0.113	0.445	0.001

Table 2.9: Holistic efficiency and technical-economic scores for MFH and W2S3 climate zone

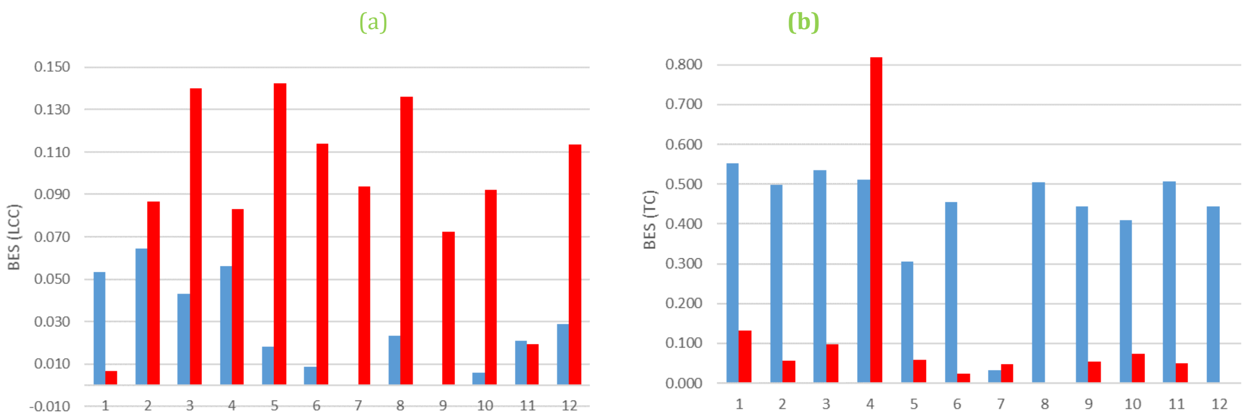

Figure 2.7: Model#1 (a) and Model#2 (b) for France (blue bars) and Spain (red bars), W2S3 climate zone

For the last considered climate zone W3S2 (Table 2.10 and Figure 2.8), model#2 suggests for both case-studies that the efficient solution is the number 6; on the contrary, model#1 does not agree in highlighting a univocal efficient solution but it suggest to adopt different solutions in the analysed Countries.

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(FR = France, POS16 and SP = Spain, POS12)

SOLUTIONS	MODEL#1		MODEL#2	
	FR	SP	FR	SP
1	0.026	0.068	0.582	0.048
2	0.045	0.051	0.549	0.160
3	0.038	0.029	0.645	0.022
4	0.059	0.024	0.643	0.040
5	0.021	0.063	0.369	0.064
6	0.009	0.041	0.038	0.038
7	0.035	0.048	0.615	0.092
8	0.015	0.077	0.467	0.195
9	0.045	0.020	0.662	0.089
10	0.060	0.032	0.660	0.132
11	0.002	0.123	0.236	0.938
12	0.021	0.075	0.522	0.059

Table 2.10: Holistic efficiency and technical-economic scores for MFH and W3S2 climate zone

(a) **(b)**

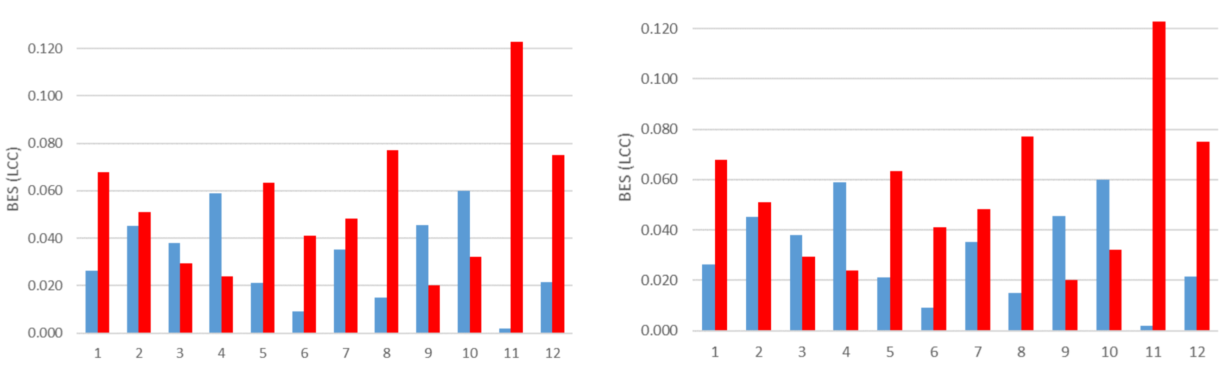

Figure 2.8: Model#1 (a) and Model#2 (b) for France (blue bars) and Spain (red bars), W3S2 climate zone

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2.3 Discussion

In order to discuss results, it is interesting to consider holistic efficiency scores together with some characteristics of solutions.

Table 2.11. and Table 2.12 report, respectively for single-family and multifamily houses, the amounts of primary energy consumption (kWh/m^2) and of Life Cycle Cost (€/m^2) for each solution and climate zone.

Notice that in order to calculate the LCC estimates, the initial investment is considered and, at the same time the LCC has been considered as input for the model#1 applied for computing the holistic efficiency of solutions.

On the contrary, the primary energy consumption could have been a bad output or an input for the frontiers, because, together with the LCC are key-variables in finding the optimal solution. However, the sample size does not allow to obtain robust results with an input-output space bigger than those used. For this reason, in both model the good output to maximize has been represented by the total final energy saving in order to consider together with CO_2 emissions the effects on consumptions.

As discussed before, the Life Cycle Assessment is recognized as the most appropriate methodology in order to evaluate the impact on social and health systems due to a production process, as, for instance, the retrofitting interventions. However, a high availability of data is necessary for computing the life cycle assessment and in this work a combination of life cycle cost and directional distance function has been adopted for evaluating which solutions for each typology of buildings and climate zone are efficient.

We can observe that, in general, the obtained efficiency scores do not always match with the minimum values of Primary Energy Consumption.

Indeed, considering the case of single-family house and W1S2 climate zone, the solution 9 is the best in terms of efficiency (Table 2.3.) and it does not correspond to the minimum LCC evaluation but it is the best solution considering the primary energy consumption. The proposed scores measure which solution has the minimum impact on environment, in terms of CO_2, and the maximum capacity in energy saving, taking equal the LCC (model#1) or total costs (model#2). We could conclude that results are contradictory but the meaning of LCC and efficiency score are different. Results suggest that considering only LCC, the solution 9 is not the best one but the POS 9 is the most efficient considering not only the LCC but also the impact in terms of energy savings and emissions.

Considering this specific case, from Table 2.11 solution 1 presents the lower LCC values but Table 2.3 suggests that it is not the most efficient because the efficiency score is higher than 0, rather it is the worst in terms of produced outputs and also the primary energy consumption is very high compared with other alternatives.

Similar results are obtained in the case of multifamily houses and W1S2 climate zone (Table 2.7). Indeed, also in this situation, models agree in highlighting solution 8 as the more efficient. Table 2.12 shows that this solution does not present the minimum value of LCC estimation but in terms of initial energy, consumption is the best choice.

Nevertheless, considering all results of efficient frontiers and values of primary energy consumptions, it is not so clear which solution is able to combine all factors affecting the choice to do retrofitting interventions.

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For this reason and in order to explain better results, we propose the scatterplots for each typology of buildings and climate zones where the efficiency scores, calculated with LCC (i.e., holistic efficiency scores, model#1) represent the values on abscissa axis and the values of primary energy consumption are placed on ordinate axis.

These figures allow to evaluate the best solution considering the holistic evaluation of efficiency scores and the primary energy consumptions. These representations clearly suggest to choose the solutions near to the origin of axes where the holistic efficiency is at its maximum and the primary energy consumption is at its minimum. The bullet points in the figures represent the solutions, as described in the near tags.

Figure 2.9 shows the plot referring to the single-family houses and climate zone W1S2. In this case the graph confirms previous considerations and for Cyprus the solution 9 is the best one as in the case of Croatia.

Figure 2.10 considers W2S2 climate zone and if for Cyprus solutions 5, 6, and 8 can be considered as optimal; on the contrary, Croatia presents an optimal combination of efficiency scores and consumptions for solutions 2 and 3, that are not the observations the most efficient in the holistic meaning but they combine top solutions.

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SOLUTIONS	W1S2				W2S2				W2S3				W3S2			
	PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)	
	CY	HR	CY	HR	CY	HR	CY	HR	CY	HR	CY	HR	CY	HR	CY	HR
1	44.95	57.05	123.31	150.60	56.64	88.89	156.18	194.44	69.75	80.06	200.82	231.29	80.80	104.60	211.03	237.47
2	43.00	54.22	125.07	152.50	59.89	92.34	156.45	194.70	68.45	66.12	200.85	233.13	89.20	108.41	218.30	240.79
3	40.04	56.13	125.49	153.92	60.23	94.30	158.02	195.69	80.26	69.15	201.00	233.62	86.69	106.72	220.60	240.94
4	41.47	54.26	126.11	154.74	63.43	90.46	158.22	195.78	81.63	83.26	201.11	233.97	81.07	109.30	222.06	241.11
5	39.41	53.18	126.63	155.61	50.58	97.68	160.87	196.39	73.58	89.54	202.16	235.34	85.44	108.81	222.33	242.14
6	38.09	51.27	127.20	156.37	47.51	93.90	160.89	196.46	72.29	85.09	202.21	235.80	94.95	110.47	227.49	244.16
7	47.18	57.05	127.26	161.75	53.83	97.00	162.08	196.46	84.21	75.49	202.56	236.26	89.47	112.96	229.32	244.19
8	39.53	54.22	127.84	163.65	50.75	95.86	162.11	196.72	85.56	71.14	202.63	236.27	93.76	111.40	229.39	244.56
9	37.47	51.92	128.34	164.04	60.30	86.22	162.31	196.81	72.72	81.46	203.97	236.92	78.05	110.88	230.46	245.51
10	45.22	59.79	128.98	164.70	63.56	102.04	162.60	196.94	84.74	67.46	204.54	237.97	75.79	113.36	230.87	245.53
11	42.21	56.13	129.36	165.07	63.89	99.23	164.18	197.13	76.50	78.32	205.23	237.98	86.97	115.01	231.64	247.53
12	43.67	54.26	130.03	165.89	67.11	98.45	164.39	197.35	88.62	92.52	205.97	238.74	91.34	104.60	231.91	248.62

Source: Deliverable 3.4, Happen Project

Table 2.11: Primary Energy Consumption (kWh/m2) and Life Cycle Cost (€/m2) for solutions of Singlefamily houses in climate zones

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SOLUTIONS	W1S2				W2S2				W2S3				W3S2			
	PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)		PRIMARY ENERGY CONSUMPTION (KWH/M²)		LCC (€/M2)	
	FR	SP	FR	SP	FR	SP	FR	SP	FR	SP	FR	SP	FR	SP	FR	SP
1	37.94	53.59	88.24	126.69	35.72	98.97	115.21	179.60	47.89	98.92	134.84	230.05	47.90	118.51	133.17	250.20
2	41.40	49.47	88.55	128.30	34.76	73.47	115.30	180.76	49.84	94.67	135.40	233.93	50.77	118.01	133.51	250.72
3	36.75	48.95	88.90	129.78	33.26	75.50	115.82	186.37	45.76	100.29	135.52	234.32	50.49	117.20	134.61	260.84
4	40.59	50.52	89.81	133.05	34.35	78.60	115.93	192.47	47.71	127.89	136.08	235.62	53.36	117.16	134.98	261.04
5	44.06	48.57	90.15	136.38	34.22	94.14	117.03	194.81	43.17	95.80	138.16	236.52	47.90	112.24	135.62	261.71
6	38.09	51.59	90.25	143.27	33.26	71.29	117.12	195.15	44.24	97.33	138.79	239.44	44.52	115.12	135.66	262.66
7	39.39	51.52	90.45	145.19	39.40	95.20	117.30	195.91	41.03	104.86	138.80	243.34	50.77	120.00	135.97	264.77
8	36.78	47.16	90.49	145.40	38.47	69.59	117.48	195.93	45.18	96.23	138.84	243.47	47.36	124.40	135.98	265.16
9	37.64	55.90	90.56	148.95	31.78	79.04	117.66	200.07	42.08	94.68	139.40	244.54	49.96	126.56	136.32	266.57
10	40.22	53.45	90.78	151.27	32.84	102.70	117.74	201.91	43.03	104.67	139.46	245.77	52.80	123.67	136.61	267.87
11	36.84	64.95	90.81	152.93	37.02	75.37	118.07	202.68	46.25	104.50	139.46	249.33	46.35	157.03	136.96	269.14
12	41.70	64.95	90.88	154.34	38.09	93.92	118.13	208.58	49.70	122.54	140.02	249.70	50.49	117.22	137.06	273.84

Source: Deliverable 3.4, Happen Project

Table 2.12: Primary Energy Consumption (kWh/m2) and Life Cycle Cost (€/m2) for solutions of Multifamily houses in climate zones

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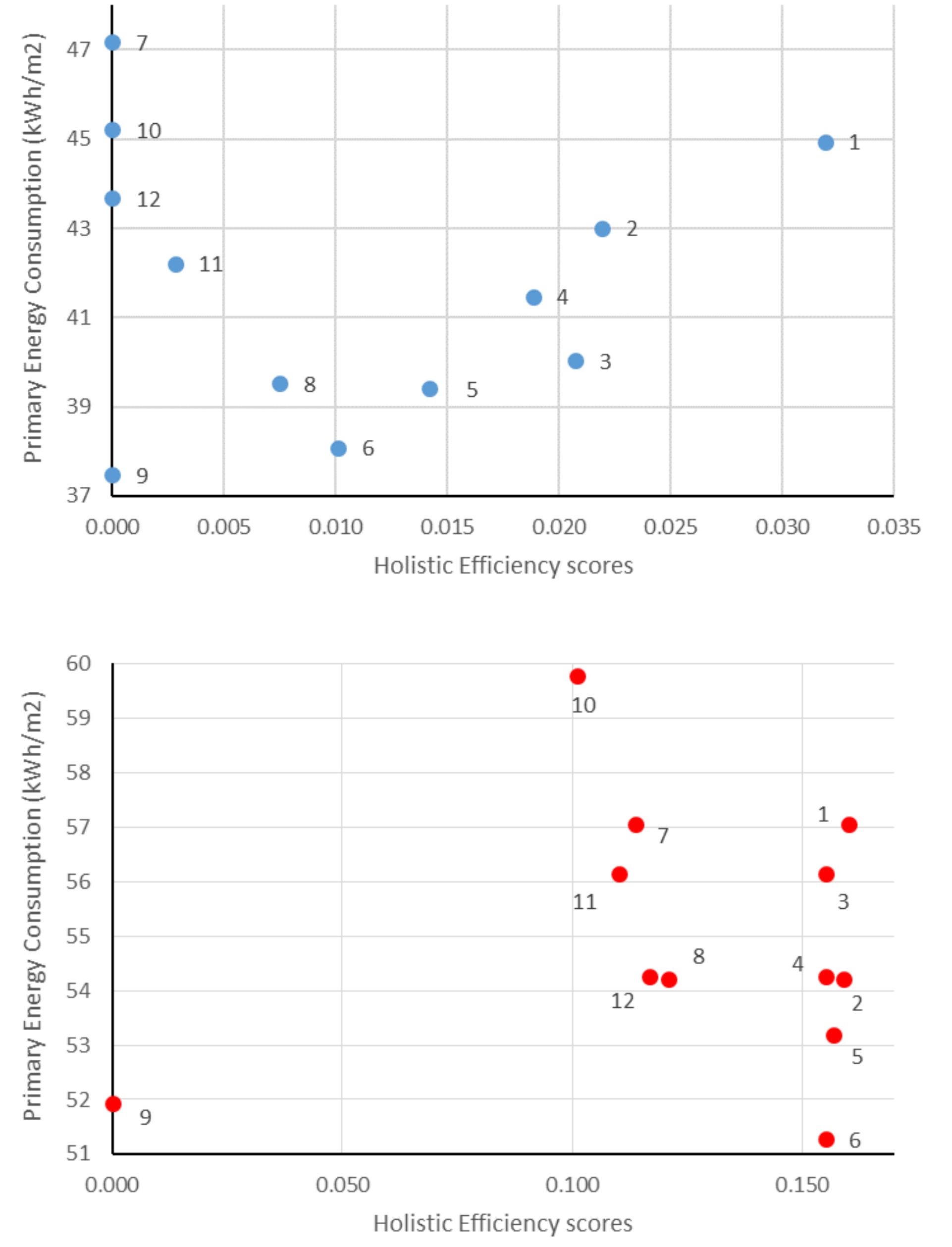

Figure 2.9: Plot of holistic efficiency scores and primary energy consumptions (kWh/m²) for singlefamily houses and W1S2 climate zone. Cyprus iblu dotse; Croatia red dots

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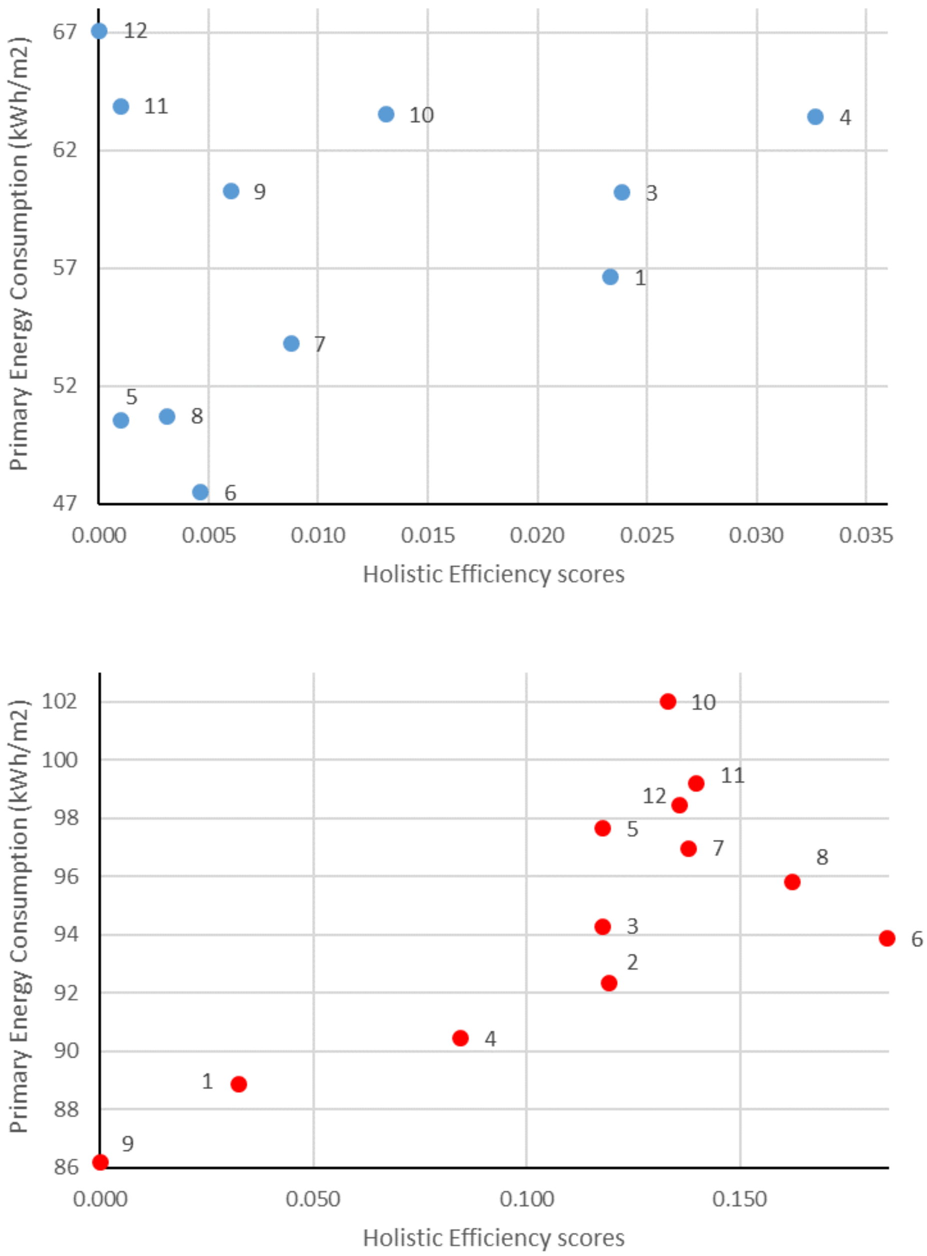

Figure 2.10: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for singlefamily houses and W2S2 climate zone. Cyprus blue dots; Croatia red dots

Figure 2.11. shows that optimal solution for W2S3 climate zone both for Cyprus and Croatia is solution 9. Considering the last climate zone (i.e., W3S2), Figure 2.12 suggests that for the first considered pilot (Cyprus) are the number 10 or 9; whereas for Croatia the best are the solutions 1, or 3, or 12.

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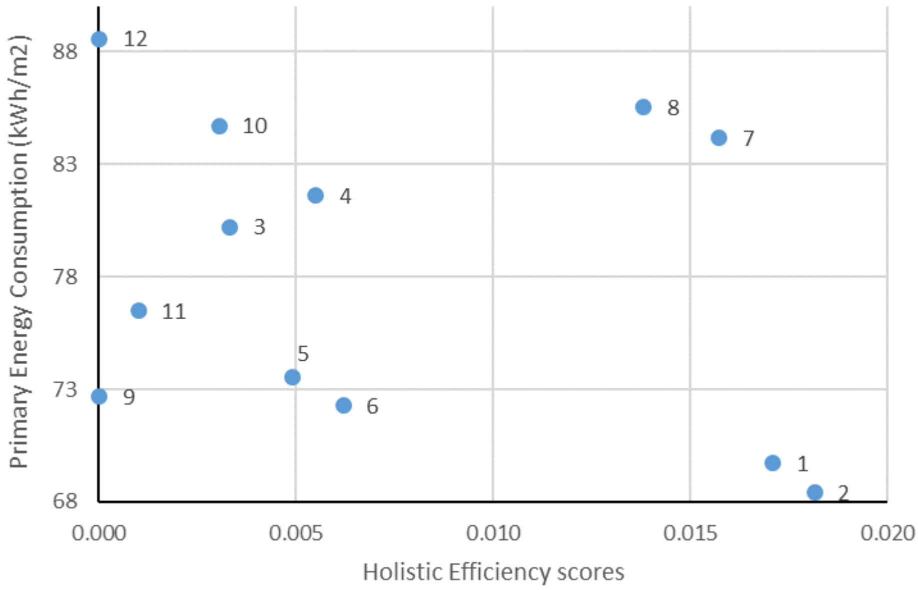

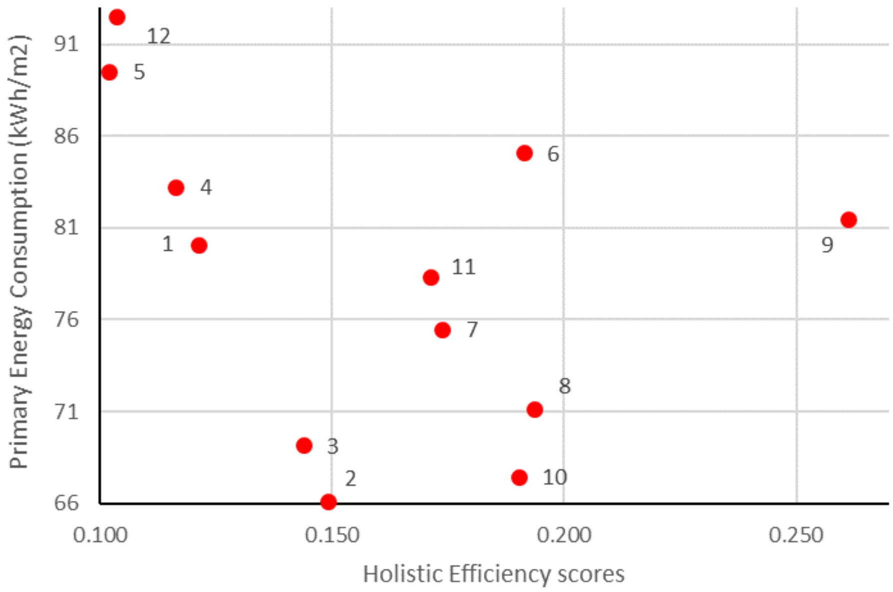

Figure 2.11: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for singlefamily houses and W2S3 climate zone. Cyprus in blue; Croatia in red

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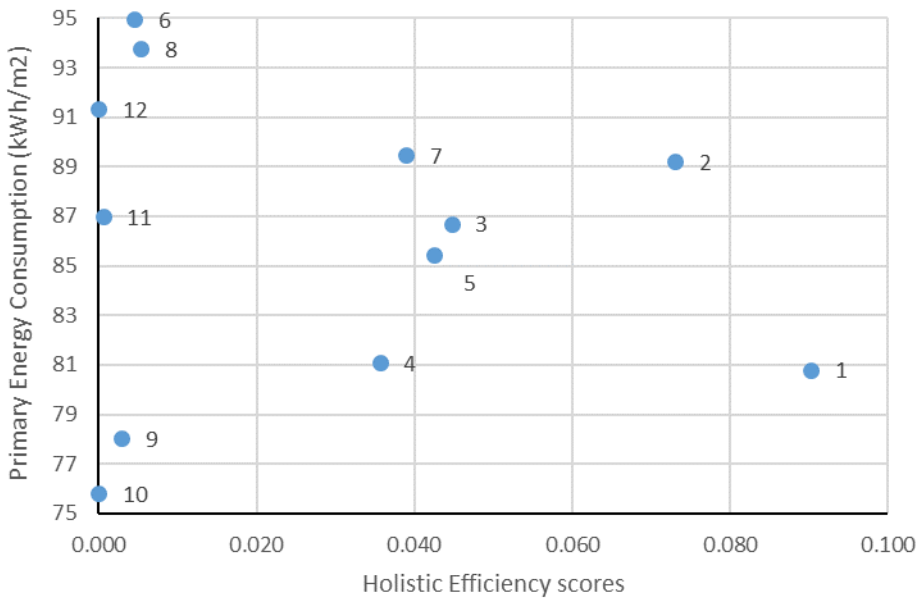

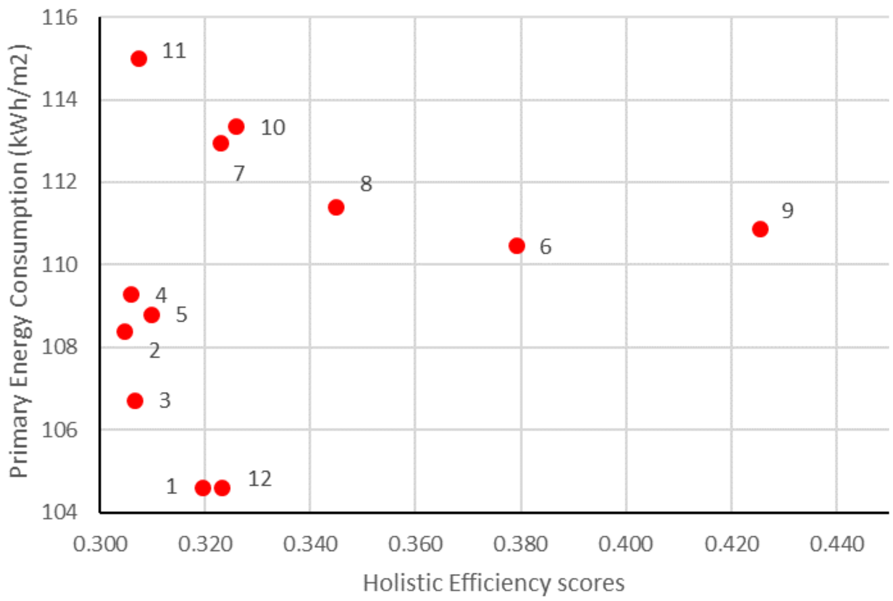

Figure 2.12: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for singlefamily houses and W3S2 climate zone. Cyprus in blue; Croatia in red

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The same analysis has been done for the case-studies referring on multifamily houses (i.e., France and Spain).

As suggested, for the first climate zone (i.e., W1S2) the choice of optimal solution is univocally identify in the solution number 8 (Figure 2.13.). For climate zone W2S2, Figure 2.14 shows that for France the best choice of intervention is the number 9; whereas for the second front-runner pilot (i.e., Spain) the optimal solutions are number 1 and 5.

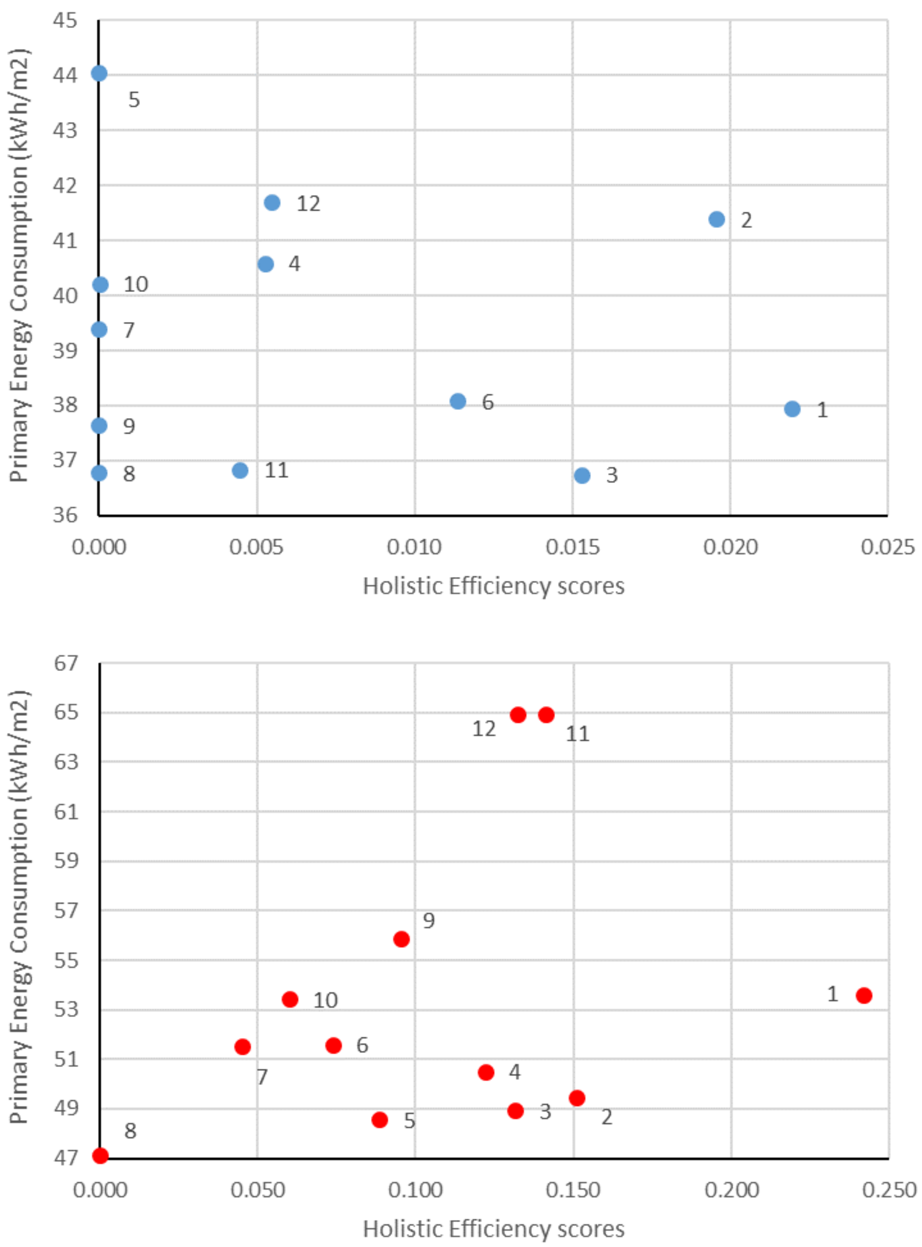

Figure2.13: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for multifamily houses and W1S2 climate zone. France in blue; Spain in red

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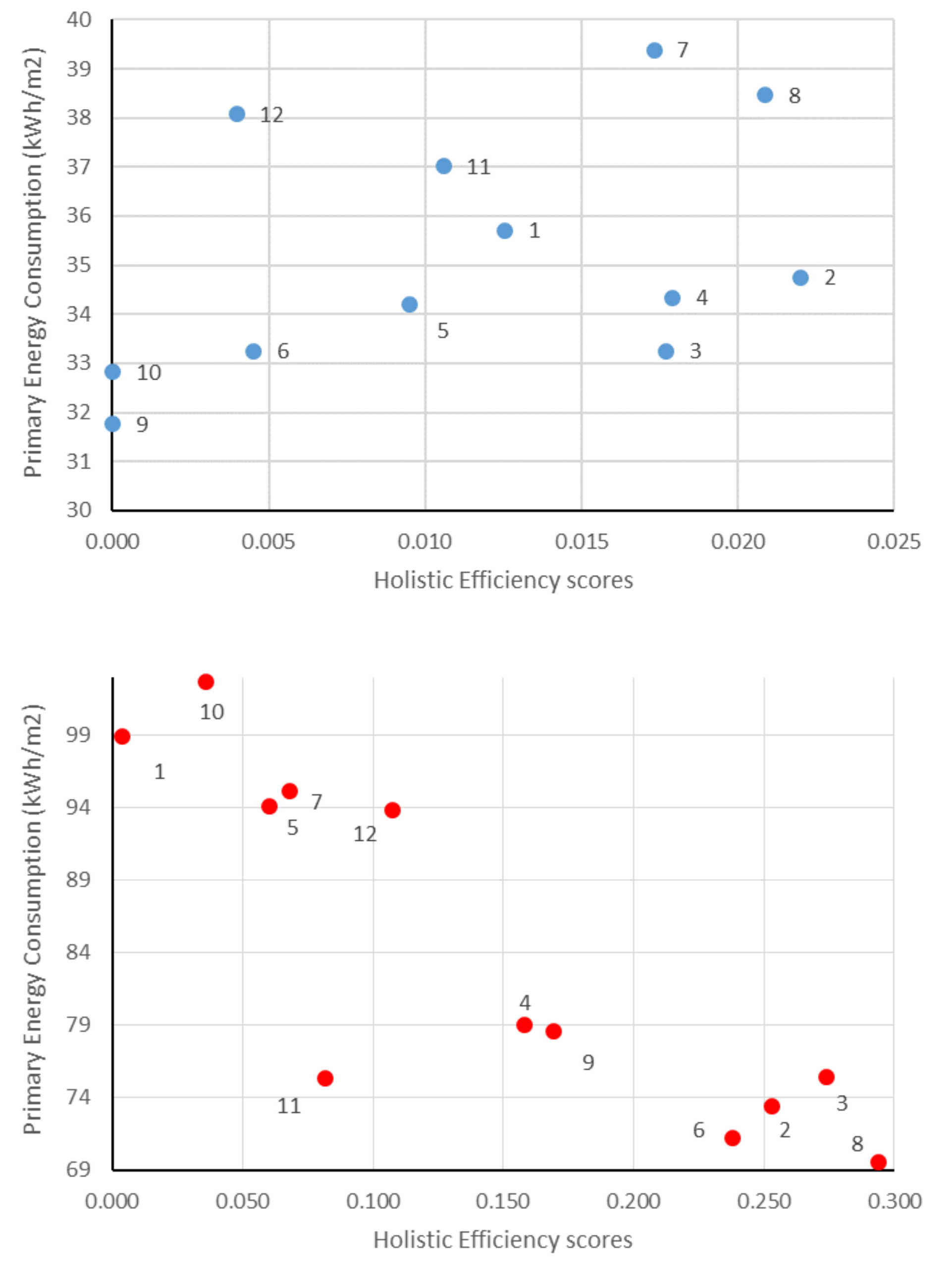

Figure 2.14: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for multifamily houses and W2S2 climate zone. France in blue; Spain in red

Figure 2.15. presents results for W2S3 climate zone where solutions 7 and 9 are optimal interventions for France. Considering the second case-study (i.e., Spain), solutions 1 and 11 are the best choice.

Finally, Figure 2.16. for France (climate zone W3S2) highlights that solutions 6 and 11 are the optimal retrofitting interventions; whereas for Spain are three the solutions more near to the origin of axes (i.e., numbers 3, 4, and 9).

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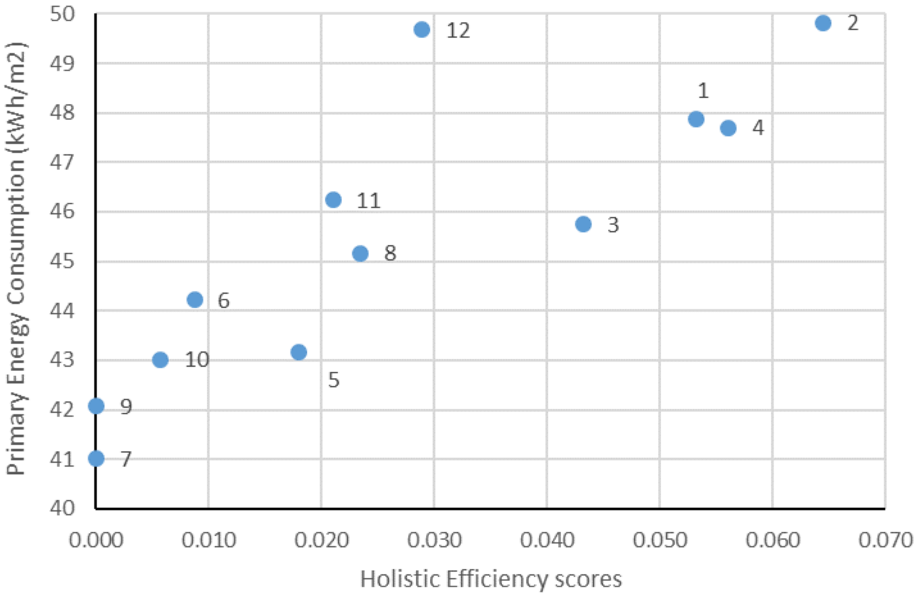

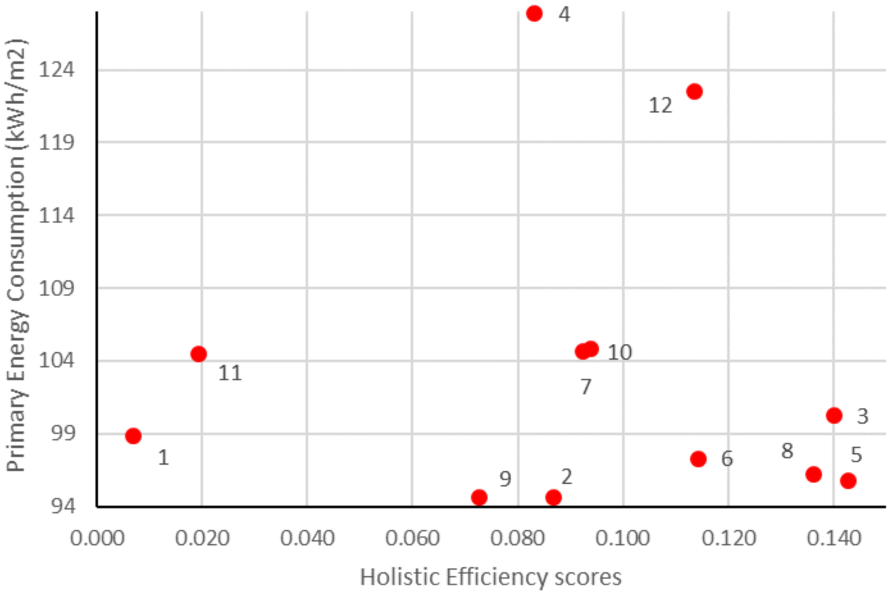

Figure 2.15: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for multifamily houses and W2S3 climate zone. France in blue; Spain in red

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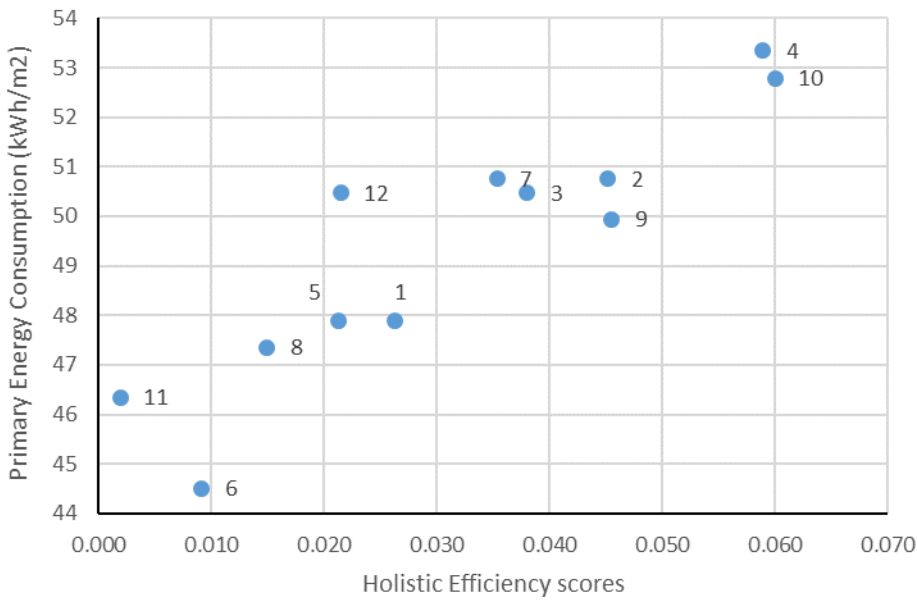

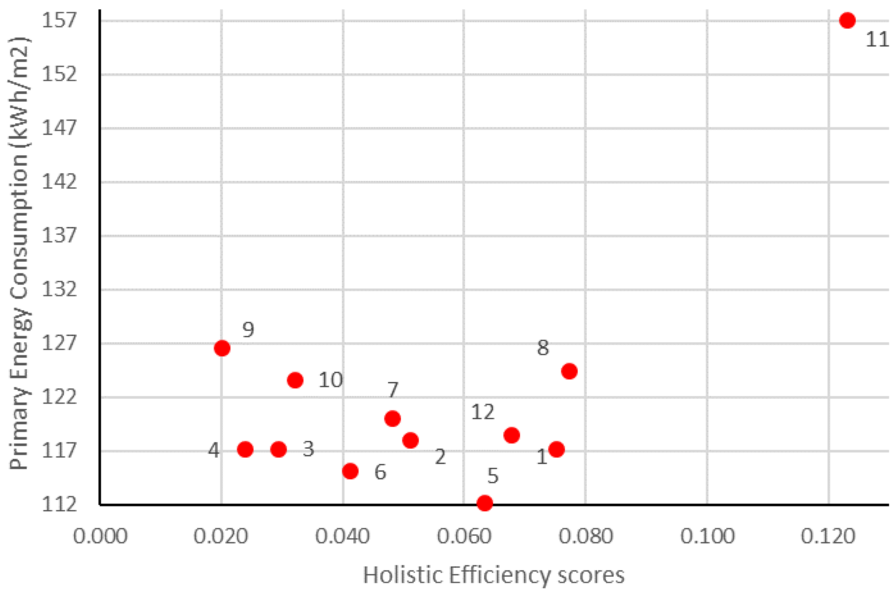

Figure 2.16: Plot of holistic efficiency scores and primary energy consumptions (kWh/m2) for multifamily houses and W3S2 climate zone. France in blue; Spain in red

2.4 Conclusion

In conclusion, starting from data collected in Happen project (mainly in deliverable D 3.4), we built a friendly methodology for computing efficiency of retrofitting interventions considering also the environmental spillovers. Indeed, the applied methodology allows to obtain a holistic efficiency score representing the ability to identify the solutions that minimize CO_2 emissions and maximize the saving of final energy consumptions. In this manner, the last scatter plots (in paragraph 2.3) enable to combine

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together the values of the holistic efficiency scores and energy consumptions necessary for interventions.

We can conclude that for Single Family Houses , according to our model, the best packages of solutions result to be:

- For climate zone W1S2: POS9 both for Cyprus and Croatia;
- For climate zone W2S2: POS5 or POS6 (Cyprus) and POS9 (Croatia)
- For climate zone W2S3: POS9 (Cyprus) and POS2 or POS3 (Croatia)
- For climate zone W3S2_ POS10 (Cyprus) and POS1 (Croatia)

Considering the Multi Family House, the best POS are the following:

- For climate zone W1S2: POS8 both for France and Spain;
- For climate zone W2S2: POS9 (France) and POS11 (Spain)
- For climate zone W2S3: POS7 (France) and POS1 or POS3 (Spain)
- For climate zone W3S2_ POS6 (France) and POS4 (Spain)

These conclusions strictly refer to the climate zones and to data introduced in the definition of the POS; for a deeper explanation and description of Optimal Solutions and of the software built for their definition, we remind to the deliverable 3.4. However, even if, as shown in the previus report 3.4, that software is very powerfull, in the present report we try to improve the research of the Optimal Solutions using an hybrid methodology, well-known in the environmental field.

The proposed methodology, that links together the Life Cycle Cost, the Directional Distance Function and the Primary Energy Savings, allows to identify the solutions most suitable to minimize the emissions (in this specific case of CO_2) maximizing the Final Energy Saving and, at the same time, considering the financial sustainability of the interventions.

The lesson that we can learn from this experiment confirms most of the results obtained by the current literature on the hybrid methodologies as effective tools in defining criteria for decision analysis of sustainability assessment ([38] and [39]).

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3 THE STOCK OF EXISTING RESIDENTIAL BUILDINGS: RESULTS OF A SURVEY AMONG THE COUNTRIES OF THE HAPPEN PROJECT

In the present chapter we will present the results of a survey conducted between the countries of the Happen project to try to understand, for each of them, the stock of existing residential buildings and, for those where the data were available, their state of energy efficiency and the level of global CO_2 emissions caused by these stocks. For each country, a single analysis will be carried out (with the construction of country files) while, for those where data will result to be comparable, cross-sectional analyses will be performed.

In order to carry out this kind of analysis we shared a template with the partners with a sheet to fill out for each Country to know the stock of buildings in their Country (the Happen project takes buildings as a reference, real estate stock consists of buildings, which could be made up of several real estate units).

The Excel sheets referring to the various Countries have been built starting from data contained in Annex A of the D 3.2 report (Catalogue of Reference building Classes in MED Countries) compiled by the same Partners, in particular starting from the first three columns (period, type and % built). Within the collaboration of seven countries, in D3.2 HAPPEN dealt with the development of a harmonized structure for residential building typologies. A set of typical residential buildingswas developed for each participant country and data in terms of construction time and building type was collected. RBs are considered as example and theoretical buildings: the categories are defined according to the building size (single family house SFH or multi flat building MFH) and their construction period. On this basis, it was decided to focus in three different construction periods (<1980, 1981-2000, 2001-2010) without taking into consideration buildings after 2010 and EPBD's issuing because they may not need refurbishment. The grouping into the three age categories can be seen as a way to simplify the overview but may mask many specificities. In particular, some of the identified building types show an overlapping of the age groups, meaning that one building type includes buildings from the other groups. In this respect, in D 3.2 report the residential building types were reduced in order to minimize the noise created by complex definitions, errors and misunderstandings. More specifically, SFH definition will also include terraced houses and MFH will include apartment blocks.
In this new survey, each partners, for each period and % of RB (as resulted from what already written in D3.2) in the excel template received had to fill in:
I. total Number of Reference Buildings (RB) divided according to the percentage breakdown between SFH and MFH for the 3 periods of construction of the buildings considered: <1980; 1981-2000; 2001-2010.

II. Regions: name of the regions of each Country;

III. Climate Zone: the Spanish partner (IVE / USE) proposed climatic zones for each Happen Country; the partners had to try to adapt them to their regions, since the climatic zones identified could be more or less than the regions indicated.

IV. Number of RB for each Region (always according to the typology of RB and the period of construction); in addition, if available, the average/total number of m^2 of the SFH and the total and average number of m^2 of the MFH (considering an average number of floors).

V. Energy certificate of the buildings, always according to the typology of RB and the period of construction. If available 3 kind of data were requested: Primary Energy Consumption, (PEC= $kWh/m^2.yr$) - CO_2 emissions ($kgCO_2/m^2.yr$) - letter/label of energy efficiency.

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In the following paragraphs the results of this survey will be presented with reference to each Happen country. For each of them the table with the main answers related to the stock of RB and their characteristics in terms of PEC and CO_2 emission will be described.

Anyway, even if in the questionnaire, we tried to create a common survey base for all countries, from the answers we realized that the systems for collecting the data and their subsequent availability to the public are quite different among the Happen countries; consequently the analysis of such data can't necessarily be very homogeneous. Particular difficulties, deficiencies and shortcoming have been encountered in indicating the average/total number of m² of the SFH and of the MFH (for which, i.e., it has almost never been considered an average number of floors). For this reason to complete and standardize this type of information among the countries, it was chosen to use the m² already indicated by the partners in D3.2, Annex A, collected and reworked for the current use in tab. 3.1.

Period		Total floor area m² (for Building)	N° of floors (for Building)	N°of Dwellings (for building)	Single Building Average m²	Single Dwelling Average m²
		A	B	C	D= AxB	E= AxB/C
	SPAIN					
<1981	SFH	116	2	1	232	232
	MFH	240	6	12	1.440	120
1981-2000	SFH	107	2	1	214	214
	MFH	200	6	12	1.200	100
2001-2010	SFH	65	3	1	194	194
	MFH	1.009	7	42	7.064	168
	FRANCE					
<1981	SFH	44	2	1	88	88
	MFH	198	10	30	1.980	66
1981-2000	SFH	97	1	1	97	97
	MFH	611	8	69	4.888	71
2001-2010	SFH	48	2	1	95	95
	MFH	777	6	86	4.662	54
	SLOVENIA					
<1980	SFH	106	3	1	318	318
	MFH	290	4	7	1.160	166
1981-2000	SFH	91	2	1	182	182
	MFH	421	6	40	2.526	63

2001-present	SFH	142	2	1	284	284
	MFH	2.249	7	160	15.743	98
	CROATIA					
<1980	SFH	72	1	1	72	72
	MFH	1.082	3		3.247	
1981-2000	SFH	95	1	1	95	95
	MFH	936	5		4.680	
2001-present	SFH	95	1	1	95	95
	MFH	554	5		2770	
	ITALY					
<1980	SFH	81	2	1	162	162
	MFH	540	5	40	2.700	68
1981-2000	SFH	106	2	1	212	212
	MFH	716	6	42	4.296	102
2001-present	SFH	96	2	1	192	192
	MFH	410	2	4	820	205
	CYPRUS					
<1980	SFH	56	2	1	112	112
	MFH	370	3	4	1.110	278
1981-2000	SFH	172	2	1	344	344
	MFH	580	4	4	2.320	580
2001-present	SFH	192	3	1	576	576
	MFH	740	3	9	2.220	247
	GREECE					
<1980	SFH	130	1	3	130	43
	MFH	322	4	16	1.288	81
1981-2000	SFH	107,2	1	1	107	107
	MFH	360	5	20	1.800	90
2001-present	SFH	80	2	1	160	160
	MFH	150	4	8	600	75

Source: data processing from D 3.2, Annex A

Table 3.1 – Average number of m² of the SFH and of the MFH in Happen Countries

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3.1 Main characteristics and trend of the Buildings Stock in Spain

The results of the survey with reference to Spain are summarized in table 3.3 with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of primary energy consumption and CO_2 emission referred to the three different construction periods chosen (<1980, 1981-2000, 2001-2010).

Spain is divided into 20 principal regions that correspond mainly to the climate zones coloured in yellow, shown in table 3.2:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.2 : Spain, main climate zones (in yellow) resulting from the survey

Consequently, apart from exceptions, the climate is never extreme (too hot or too cold), with a prevalence of warm weather.

The total stock is of 10.567. 091 buildings, built for about the 50% before of 1980 and only about 20% after 2001, then rather old and with a strong prevalence (about 75%) of SFH.

The average data related to the Primary Energy Consumption, (PEC, kWh/m^2.yr) of the buildings of the three period of time considered, are synthesized in fig 3.1 (expressed in natural logarithm, ln); which related to the CO_2 emissions (kgCO_2/m^2.yr) are shown in fig. 3.2.

The regions with the highest PEC value and CO_2 emissions (for each m^2 every year) are Castilla Leon, Mancha and Madrid in all the periods considered, both for SFH and MFH. (tab.3.3)

Both PEC and CO_2 emissions have dropped considerably over time: buildings subsequent to 2001 have average values equal to approximately 40% and 35% respectively of those built before 1980.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of building (of the three period considered), are synthesized in fig. 3.3 (expressed in absolute values and then in natural logarithm); which related to the total CO_2 emissions (kgCO_2/total m^2.yr), are shown in fig.3.4.

The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding Primary energy consumption and CO_2 values (calculated as the average across all regions).

As we can see from the graphs, while the trends relating to the SFH continue to decrease over time even if we consider the total m^2, as regards the MFH the trend is instead increasing, both for PEC and for CO_2. This depends on the fact that over time the average size of the MFH buildings has grown (in terms of number of floors and number of dwellings), therefore, while decreasing the level of energy consumption and CO_2 emissions at the unit level, on the total m^2 the values have risen, especially after 2010.

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Period	Type	N° of RFs	Region	Climate zone	N° of RFs	Energy Certificate		
						Primary energy consumption (kWh/m².yr)	CO_2 emissions ($kgCO_2/m^2.yr$)	Letter energy efficiency
< 1980	SFH	4.394.382	ANDALUCIA	W1S3-W2S3	828.451	268,7	64,3	F
			ARAGON	W2S2	164.473	409,25	91,5	F
			ASTURIAS	W2S1	108.703	279,55	65,85	F
			BALEARES	W1S2	122.699	263,35	72,5	F
			CANARIAS	W0S2	184.765	216,3	60,5	F
			CATALUÑA	W2S2	465.548	295,65	69,05	F
			CASTILLA LEON	W2S2-W3S2	473.883	480,2	111	F
			CASTILLA LA MANCHA	W2S2-W2S3	359.238	424,4	92,05	F
			EXTREMADURA	W2S3	221.171	344,75	78,95	F
			GALICIA	W2S1	398.768	279,55	65,85	F
			MURCIA	W1S2	161.951	249,1	59,6	F
			NAVARRA	W3S1	52.805	378,1	83,3	F
			PASI VASCO	W2S1	45.949	279,55	65,85	F
			RIOJA	W2S1	31.886	409,25	91,5	F
			VALENCIA	W1S2	436.947	249,1	59,6	F
			MADRID	W2S2	139.130	424,4	92,05	F
			CANTABRIA	W2S1	54.870	279,55	65,85	F
			CEUTA	W1S2	139.130	263,35	72,5	F
			MELILLA	W1S2	4.015	216,3	60,5	F
	MFH	1.215.336	ANDALUCIA	W1S3-W2S3	174.153	192,6	46,1	F
			ARAGON	W2S2	36.663	308,9	68,35	F
			ASTURIAS	W2S1	30.718	213	50,45	F
			BALEARES	W1S2	37.353	191,45	53,65	F
			CANARIAS	W0S2	59.151	153,4	43,15	F
			CATALUÑA	W2S2	232.383	226,7	53,15	F
			CASTILLA LEON	W2S2-W3S2	66.960	389,3	89,95	F
			CASTILLA LA MANCHA	W2S2-W2S3	51.035	317,45	72,95	F
			EXTREMADURA	W2S3	32.765	252,4	58,5	F
			GALICIA	W2S1	81.766	213	50,45	F
			MURCIA	W1S2	33.998	181,55	44,2	F
			NAVARRA	W3S1	16.405	295	65,85	F
			PAIS VASCO	W2S1	61.022	213	50,45	F
			RIOJA	W2S1	10.822	308,9	68,35	F
			VALENCIA	W1S2	163.291	181,55	44,2	F
			MADRID	W2S2	108.795	317,45	72,95	F
			CANTABRIA	W2S1	15.538	213	50,45	F
			CEUTA	W1S2	1.288	191,45	53,65	F
			MELILLA	W1S2	1.230	153,4	43,15	F
1981-2000	SFH	2.224.634	ANDALUCIA	W1S3-W2S3	567.805	250,45	44,1	E
			ARAGON	W2S2	49.423	278,35	62	E
			ASTURIAS	W2S1	22.700	196,25	44,7	E
			BALEARES	W1S2	45.183	188,5	51	E
			CANARIAS	W0S2	91.736	154,1	41,95	E
			CATALUÑA	W2S2	258.484	213,05	48,85	E
			CASTILLA LEON	W2S2-W3S2	173.546	336,85	76,9	E
			CASTILLA LA MANCHA	W2S2-W2S3	204.275	292,45	65,5	E
			EXTREMADURA	W2S3	104.741	238,35	55,05	E
			GALICIA	W2S1	144.228	196,25	44,7	E
			MURCIA	W1S2	94.193	175,85	41,5	E
			NAVARRA	W3S1	22.009	262,85	58,25	E
			PAIS VASCO	W2S1	19.505	196,25	44,7	E

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			RIOJA	W2S1	7.982	278,35	62	E
			VALENCIA	W1S2	222.306	175,85	41,5	E
			MADRID	W2S2	175.195	292,45	65,5	E
			CANTABRIA	W2S1	18.341	196,25	44,7	E
			CEUTA	W1S2	889	188,5	51	E
			MELILLA	W1S2	2.093	154,1	41,95	E
	MFH	792.425	ANDALUCIA	W1S3-W2S3	116.579	134,55	31,9	E
			ARAGON	W2S2	15.065	210,5	46,85	E
			ASTURIAS	W2S1	45.222	146,7	33,45	E
			BALEARES	W1S2	15.509	135,7	36,8	E
			CANARIAS	W0S2	32.321	108,25	29,55	E
			CATALUÑA	W2S2	77.928	158,2	36,25	E
			CASTILLA LEON	W2S2-W3S2	33.263	259,45	59,3	E
			CASTILLA LA MANCHA	W2S2-W2S3	30.261	220,7	49,35	E
			EXTREMADURA	W2S3	20.108	176,4	40,7	E
			GALICIA	W2S1	33.233	146,7	33,45	E
			MURCIA	W1S2	21.277	126,9	30	E
			NAVARRA	W3S1	6.556	200,05	44,3	E
			PAIS VASCO	W2S1	14.388	146,7	33,45	E
			RIOJA	W2S1	3.643	210,5	46,85	E
			VALENCIA	W1S2	62.178	126,9	30	E
			MADRID	W2S2	229.242	220,7	49,35	E
			CANTABRIA	W2S1	34.430	146,7	33,45	E
			CEUTA	W1S2	453	135,7	36,8	E
			MELILLA	W1S2	769	108,25	29,55	E
2001-2010	**SFH**	1.218.021	ANDALUCIA	W1S3-W2S3	276.364	105,25	24,5	D
			ARAGON	W2S2	26.049	164,45	37	D
			ASTURIAS	W2S1	20.279	114,2	25,7	D
			BALEARES	W1S2	27.126	109,05	28,6	D
			CANARIAS	W0S2	44.442	88,35	23,45	D
			CATALUÑA	W2S2	106.407	126,75	28,8	D
			CASTILLA LEON	W2S2-W3S2	125.727	193,15	43	D
			CASTILLA LA MANCHA	W2S2-W2S3	130.810	172,7	39,05	D
			EXTREMADURA	W2S3	38.458	140,45	32,15	D
			GALICIA	W2S1	115.894	114,2	25,7	D
			MURCIA	W1S2	64.242	99,15	22,8	D
			NAVARRA	W3S1	16.788	155,95	34,95	D
			PASI VASCO	W2S1	13.073	114,2	25,7	D
			RIOJA	W2S1	6.358	164,45	37	D
			VALENCIA	W1S2	121.891	99,15	22,8	D
			MADRID	W2S2	65.858	172,7	39,05	D
			CANTABRIA	W2S1	16.365	114,2	25,7	D
			CEUTA	W1S2	1.156	109,05	28,6	D
			MELILLA	W1S2	734	88,35	23,45	D
	MFH	722.293	ANDALUCIA	W1S3-W2S3	43.692	69,4	16,1	D
			ARAGON	W2S2	7.369	112,5	25,35	D
			ASTURIAS	W2S1	4.409	77,05	17,35	D
			BALEARES	W1S2	69.798	71,6	18,85	D
			CANARIAS	W0S2	114.582	56,6	15,1	D
			CATALUÑA	W2S2	32.512	85,4	19,4	D
			CASTILLA LEON	W2S2-W3S2	286.060	133,8	29,85	D
			CASTILLA LA MANCHA	W2S2-W2S3	13.437	118,25	26,75	D
			EXTREMADURA	W2S3	5.819	94,75	21,7	D
			GALICIA	W2S1	18.817	77,05	17,35	D
			MURCIA	W1S2	12.159	65,05	15	D
			NAVARRA	W3S1	4.329	107,15	24	D
			PASI VASCO	W2S1	9.705	77,05	17,35	D

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			RIOJA	W2S1	3.427	112,5	25,35	D
			VALENCIA	W1S2	33.280	65,05	15	D
			MADRID	W2S2	20.219	118,25	26,75	D
			CANTABRIA	W2S1	41.782	77,05	17,35	D
			CEUTA	W1S2	326	71,6	18,85	D
			MELILLA	W1S2	571	56,6	15,1	D
Total		**10.567.091**			**10.567.091**			

Table 3.3 - Buildings stock in Spain, structure, Primary energy consumption and CO2 emissions

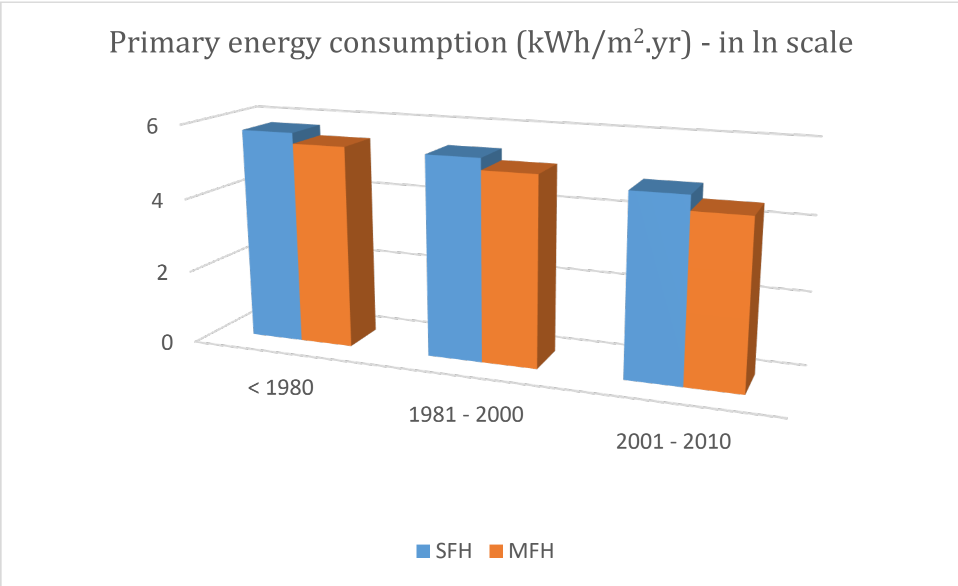

Figure 3.1– Spain: Buildings stock, Primary energy consumption per m² (kWh/m².yr)

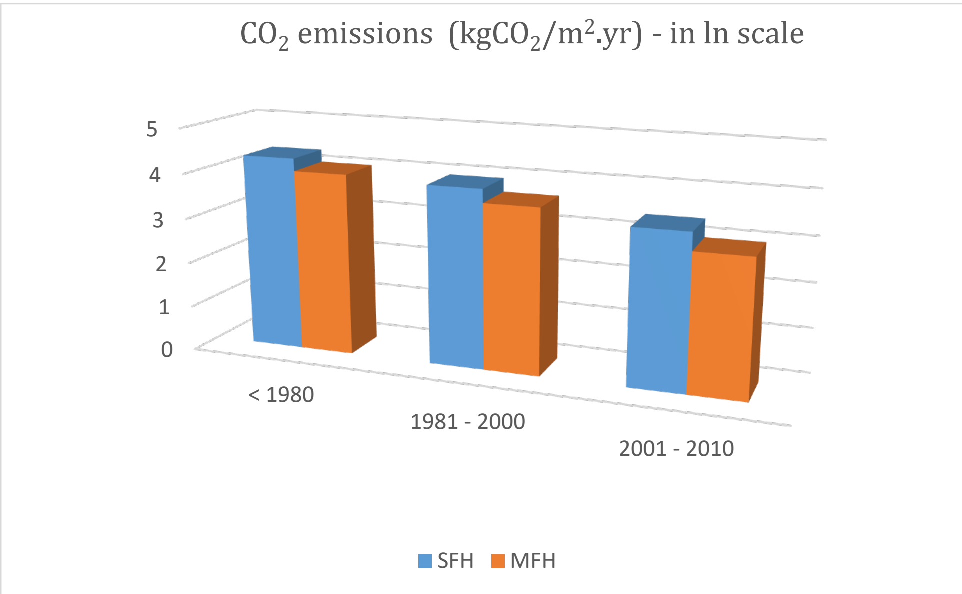

Figure 3.2 – Spain: buildings stock, CO_2 emissions per m² ($kgCO_2$/ m².yr)

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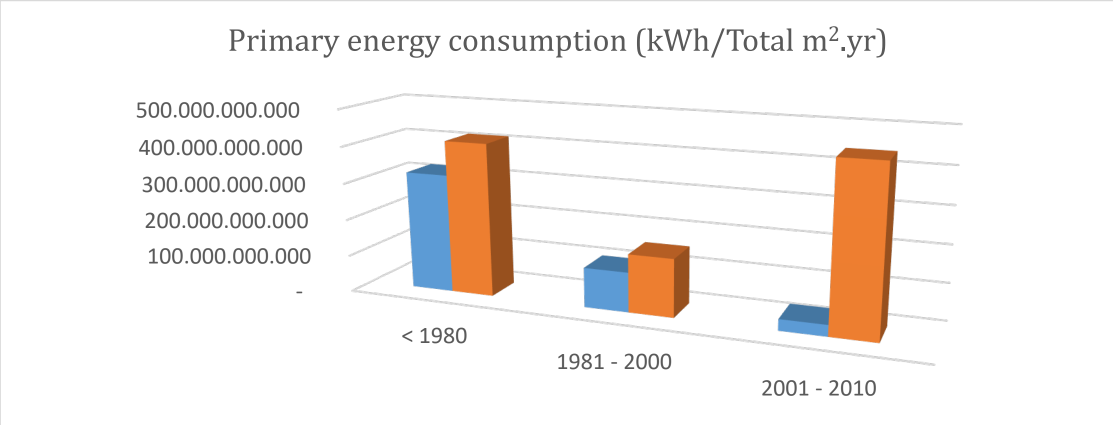

	< 1980	1981 - 2000	2001 - 2010
SFH	322.504.342.573	107.066.566.938	30.338.507.134
MFH	415.737.021.676	156.126.910.026	442.187.576.540

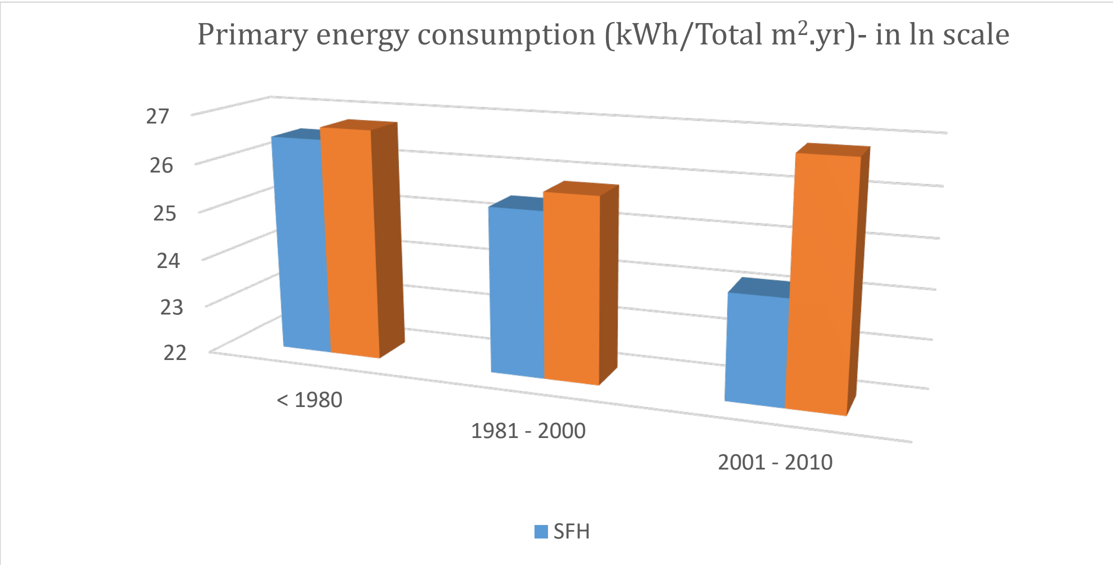

Figure 3.3 – Spain: Buildings stock, Total Primary energy consumption (kWh/total m².yr)

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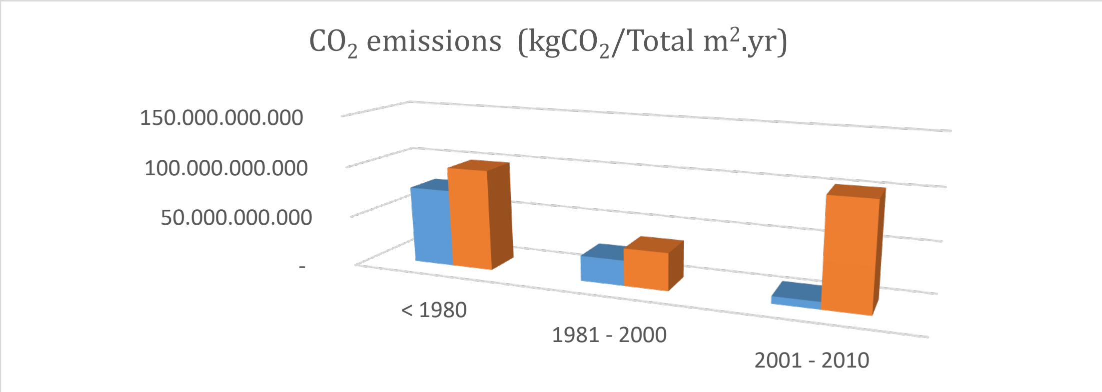

	< 1980	1981 - 2000	2001 - 2010
SFH	76.317.370.964	24.748.027.577	7.045.802.740
MFH	99.473.844.369	36.602.527.816	102.725.971.583

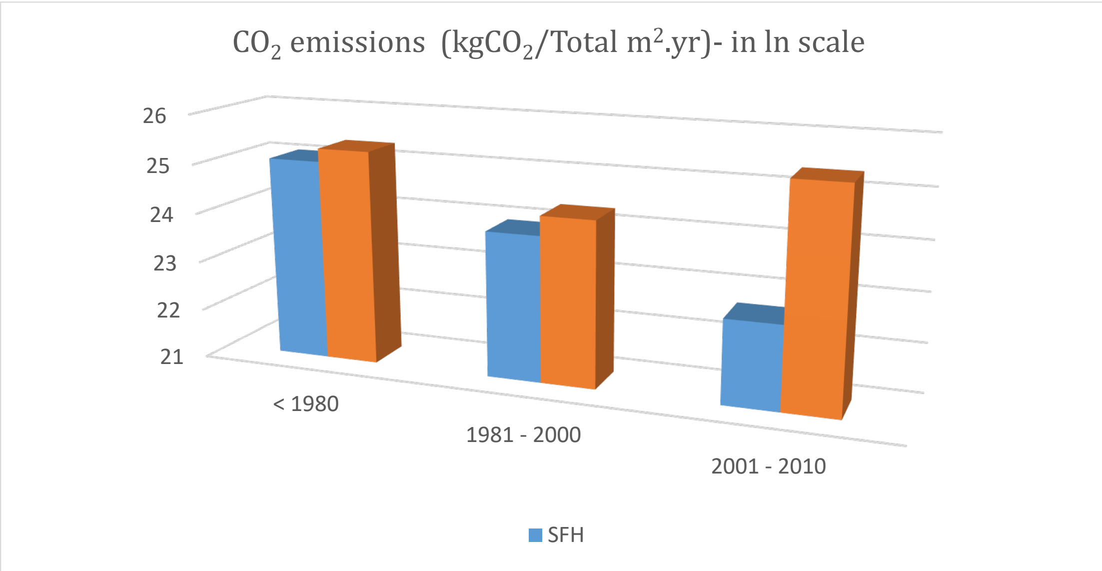

Figure 3.4 – Spain: buildings stock, total CO_2 emissions (kgCO_2/Total m^2.yr)

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3.2 Main characteristics and trend of the Buildings Stock in Slovenia

The results of the survey carried out in Slovenia are summarized in table 3.5 with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of PEC and CO_2 emission referred to the three construction periods chosen (<1980, 1981-2000, 2001-2010).

Slovenia is divided into 12 principal regions that correspond mainly to the climate zone colored in yellow, shown in table 3.4:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.4 : Slovenia, main climate zones (in yellow) resulting from the survey

Consequently, with a strong prevalence of W3S1, the climate is somewhat cold, with cold winters and fresh summers.

The total stock is of 21.375 buildings, built for about the 61% before of 1980 and only about 16% after 2001, then rather old and with a little prevalence (about 55%) of SFH.

The average data related to the PEC (kWh/m^2.yr) of the buildings of the three period considered, are synthesized in fig 3.5 (expressed in natural logarithm, ln); which related to the CO_2 emissions (kgCO_2/m^2.yr) are shown in fig. 3.6.

The values of PEC and of CO_2 emissions are not too different between the various regions; however Pomurska has the highest PEC almost in all the periods considered, both for SFH and MFH, slightly overtaken by Primorsko-notranjska (a cold region W4S1) in few cases (tab.3.5). About the CO_2 emissions, beyond Pomurska, also Zasavska present often hight level and in the last period (for the MFH).

Both PEC and CO_2 emissions have dropped considerably over time: buildings subsequent to 2001 have average values equal to approximately 50% of those built before 1980.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of building , are synthesized in fig. 3.7 (expressed in absolute values and then in natural logarithm); which related to the total CO_2 emissions (kgCO_2/total m^2.yr) are shown in fig.3.8.

The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding PEC and CO_2 values (calculated as the average across all regions).

As we can see from the graphs, while the trends relating to the SFH continue to decrease over time even if we consider the total m^2, as regards the MFH the trend is instead strongly increasing, both for PEC and for CO_2 in the last period, after 2001. This depends on the fact that over time the average size of the MFH buildings has grown (mainly in terms of total floor area and of number of dwellings per floor, tab.3.1),

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therefore, while decreasing the level of energy consumption and CO_2 emissions at the unit level, on the total m² the values have risen.

Period	**Type**	**N°. of RF**	**Region**	**Climate Zone**	**N°. of RF**	**Avg. Net floor area (m²)**	**Energy Certificate**		
							Primary energy consumption (kWh/m².yr)	**CO_2 emissions ($kgCO_2/m^2.yr$)**	**Letter energy efficiency**
< 1980	**SFH**	7.666	obalno-kraška regija	W2S2	468	125	319,67	69,26	F
			goriška	W2S2	563	131	254,02	52,73	F
			primorsko-notranjska	W4S1	160	153	269,90	56,83	G
			osrednjeslovenska	W2S1	1744	170	269,08	57,76	F
			gorenjska	W4S1	621	163	300,16	64,62	F
			jugovzhodna slovenija	W3S1	543	135	280,97	59,55	G
			zasavska	W3S1	190	154	293,17	64,27	F
			savinjska	W3S1	1015	147	277,97	60,96	F
			koroška	W4S1	166	150	258,42	53,31	F
			posavska	W3S1	340	131	288,66	62,45	G
			podravska	W3S1	1272	140	314,30	68,83	F
			pomurska	W3S1	584	125	321,05	67,98	G
	MFH	5.426	obalno-kraška regija	W2S2	256	289	258,52	55,98	D
			goriška	W2S2	290	145	235,60	50,70	D
			primorsko-notranjska	W4S1	128	464	229,13	49,08	E
			osrednjeslovenska	W2S1	1724	752	231,69	55,53	D
			gorenjska	W4S1	479	324	258,00	57,37	D
			jugovzhodna slovenija	W3S1	264	231	239,84	50,67	E
			zasavska	W3S1	148	396	260,54	62,41	E
			savinjska	W3S1	636	627	235,29	56,59	E
			koroška	W4S1	208	318	241,10	55,15	E
			posavska	W3S1	89	305	236,57	52,99	E
			podravska	W3S1	940	323	270,53	61,17	D
			pomurska	W3S1	264	290	273,53	61,09	E
1981-2000	**SFH**	3.176	obalno-kraška regija	W2S2	179	190	225,08	49,59	E
			goriška	W2S2	122	177	210,30	45,58	E
			primorsko-notranjska	W4S1	33	176	273,00	56,36	F
			osrednjeslovenska	W2S1	833	204	191,53	41,01	E
			gorenjska	W4S1	221	214	186,61	40,79	E
			jugovzhodna slovenija	W3S1	242	151	220,25	46,65	F
			zasavska	W3S1	82	183	200,07	43,54	E
			savinjska	W3S1	428	176	213,25	46,74	E
			koroška	W4S1	84	174	193,13	40,94	E
			posavska	W3S1	124	149	209,59	44,68	F
			podravska	W3S1	637	166	220,60	47,97	E
			pomurska	W3S1	191	151	287,79	62,06	F
	MFH	1.789	obalno-kraška regija	W2S2	94	441	210,49	46,10	D
			goriška	W2S2	104	149	192,03	42,45	D
			primorsko-notranjska	W4S1	29	599	228,72	50,24	D
			osrednjeslovenska	W2S1	604	966	186,87	45,48	D
			gorenjska	W4S1	147	306	216,61	51,41	D
			jugovzhodna slovenija	W3S1	82	316	180,29	41,23	D
			zasavska	W3S1	40	638	217,78	53,40	D
			savinjska	W3S1	180	794	187,90	46,08	D
			koroška	W4S1	54	377	189,78	45,46	D
			posavska	W3S1	40	170	204,58	47,28	D
			podravska	W3S1	294	552	206,68	48,17	D

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			pomurska	W3S1	121	480	216,30	52,81	D
2001-2010	**SFH**	1.610	obalno-kraška regija	W2S2	149	172	164,04	35,11	D
			goriška	W2S2	57	150	137,51	28,63	D
			primorsko-notranjska	W4S1	23	144	172,78	35,91	D
			osrednjeslovenska	W2S1	599	189	138,94	28,55	D
			gorenjska	W4S1	78	215	165,26	34,69	D
			jugovzhodna slovenija	W3S1	79	156	141,22	29,01	D
			zasavska	W3S1	24	175	169,58	37,58	D
			savinjska	W3S1	166	179	150,64	32,20	D
			koroška	W4S1	14	234	136,93	28,36	D
			posavska	W3S1	30	153	127,40	25,33	D
			podravska	W3S1	333	167	147,35	30,92	D
			pomurska	W3S1	58	161	170,34	36,34	D
	MFH	1.708	obalno-kraška regija	W2S2	246	475	118,86	24,26	C
			goriška	W2S2	62	212	157,31	30,94	C
			primorsko-notranjska	W4S1	32	404	163,75	39,94	D
			osrednjeslovenska	W2S1	625	728	148,60	31,50	C
			gorenjska	W4S1	94	527	159,94	34,40	D
			jugovzhodna slovenija	W3S1	54	440	136,85	28,33	C
			zasavska	W3S1	10	1.992	140,50	29,60	C
			savinjska	W3S1	168	416	126,65	26,81	C
			koroška	W4S1	26	672	151,08	32,85	C
			posavska	W3S1	10	1.132	129,90	26,40	C
			podravska	W3S1	276	438	149,04	31,13	C
			pomurska	W3S1	105	238	160,72	31,21	C
Total		**21.375**			**21.375**				

Table 3.5: Buildings stock in Slovenia, structure, primary energy consumption and CO_2 emissions

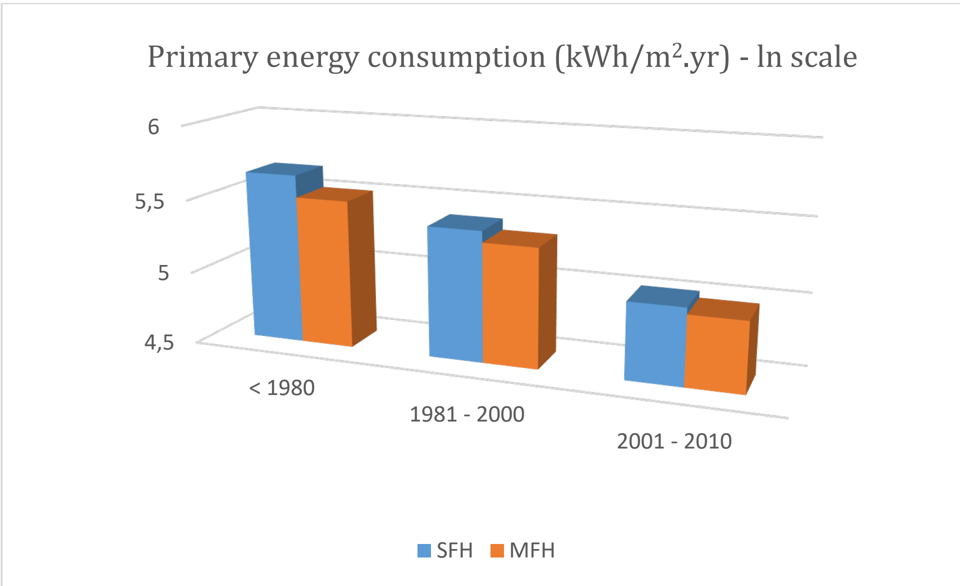

Figure 3.5 – Slovenia: Buildings stock, Primary energy consumption per m² (kWh/m².yr)

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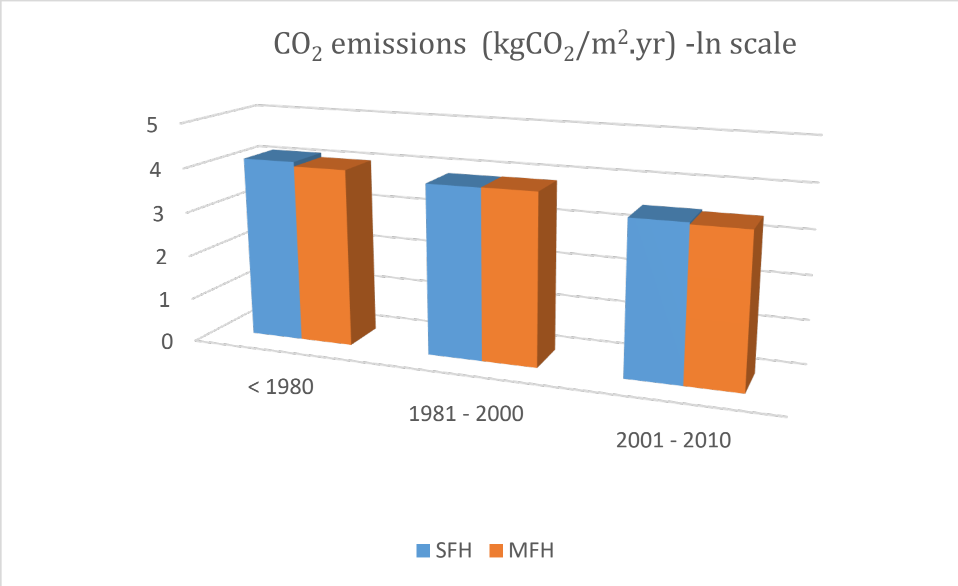
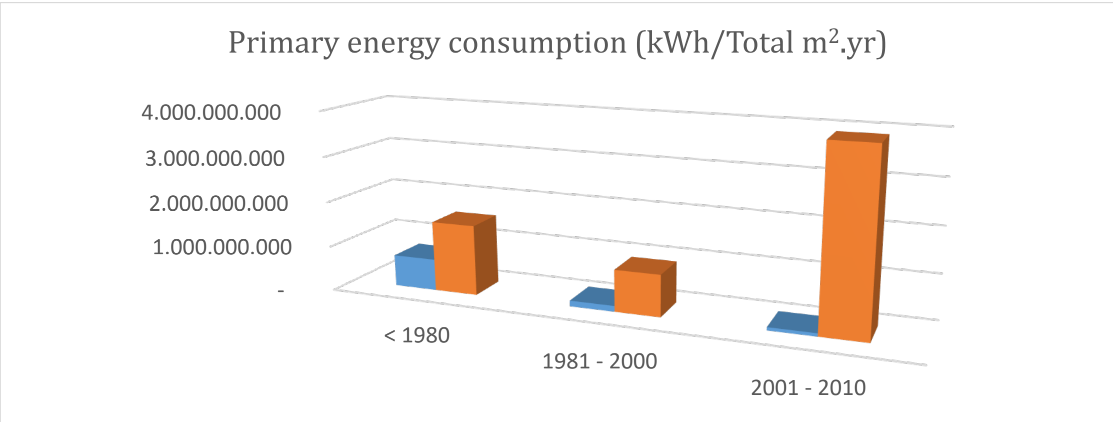


Figure 3.6 – Slovenia: buildings stock, CO_2 emissions per m^2 ($kgCO_2/m^2.yr$)



	< 1980	1981 - 2000	2001 - 2010
SFH	700.325.365	126.742.813	69.424.127
MFH	1.557.984.118	918.120.034	3.906.064.591

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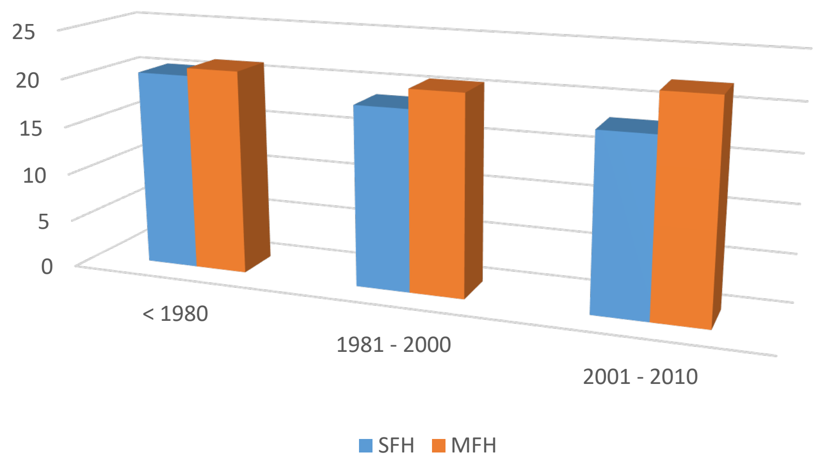
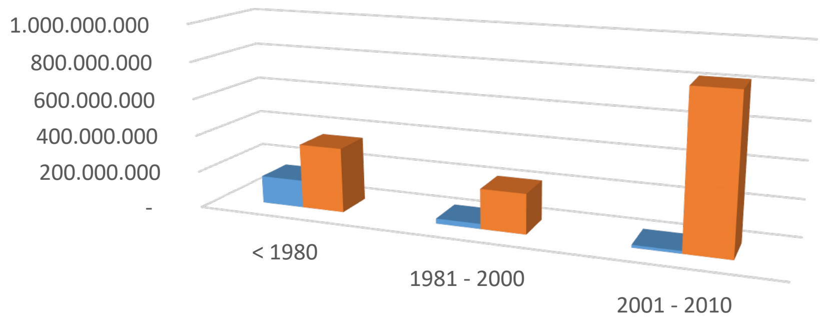


Figure 3.7–Slovenia: Buildings stock, Total Primary energy consumption (kWh/total m².yr)



	< 1980	1981 - 2000	2001 - 2010
SFH	150.038.071	27.259.385	14.580.340
MFH	350.758.869	214.694.714	823.162.109

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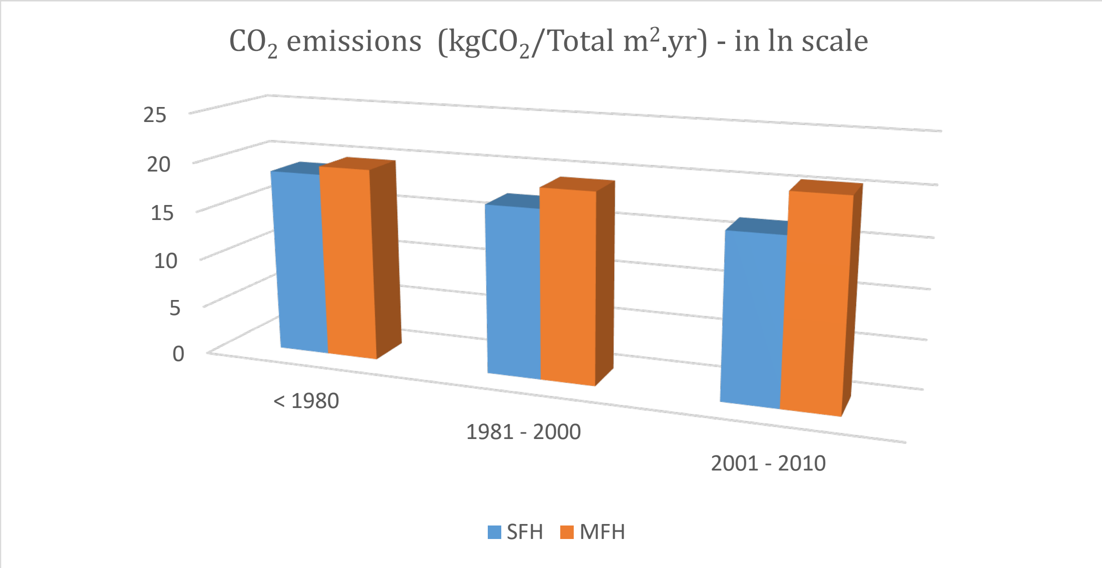

Figure 3.8 – Slovenia: buildings stock, total CO_2 emissions (kgCO_2/Total m^2.yr)

3.3 Main characteristics and trend of the Buildings Stock in Croatia

The results of the survey with reference to Croatia are summarized in table 3.7 with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of PEC referred to the three different construction periods chosen (<1980, 1981-2000, 2001-2010). Unfortunately, data on Co_2 emission are not available.

Croatia is divided into 21 principal regions that correspond mainly to the climate zone colored in yellow, as shown in Table 3.6:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.6 : Croatia, main climate zones (in yellow) resulting from the survey

With a strong prevalence of W3S1 and W3S2 the climate is somewhat cold, with rather cold winters and fresh summers.

The total stock is of 1.495.187 buildings, built for about the 64% before of 1980 and only about 10% after 2001, then quite old and fairly equally divided between SFH and MFH with a little prevalence of MFH in the last period of construction of the buildings.

The average data related to the PEC (kWh/m^2.yr) of the buildings of the three period considered, are synthesized in fig 3.9 (expressed in natural logarithm, ln). The regions with the highest PEC (for each m^2 every year) are the colder one (climate zone W3S1) and are the majority in all the periods considered,

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both for SFH and MFH. (tab.3.7). The values drop by about half in the other regions less cold (W2S2, W2S3, W3S2).

Primary energy consumption has dropped considerably over time: buildings subsequent to 2001 show average values which are less than half of those built before 1980.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of buildings are synthesized in fig. 3.10 (expressed in absolute values and then in natural logarithm).

The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding PEC values (calculated as the average across all regions).

As we can see from the graphs, the trends relating to both SFH and MFH continue the MFH to decrease over time, especially if we consider the total m^2 of the MFH; the values of the total energy consumption of the MFH are much higher because they have a number of m^2 for building, much higher than that of the SFH.

Period	Type	N° of RF	Region	Climate Zone	N° of RF	total m^2	Energy Certificate		
							Primary energy consumption (kWh/m^2.yr)	CO_2 emissions kgCO_2/m^2.yr	Letter energy efficiency
< 1980	**SFH**	460.552	Zagrebačka	W3S1	40.666	2.984.265	544		E
			Krapinsko-zagorska	W3S1	23.990	1.760.501	544		G
			Sisačko-moslavačka	W3S1	26.915	1.975.151	544		
			Karlovačka	W3S1	18.107	1.328.778	544		
			Varaždinska	W3S1	25.845	1.896.630	544		
			Koprivničko-križevačka	W3S1	19.713	1.446.634	544		
			Bjelovarsko-bilogorska	W3S1	21.629	1.587.239	544		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	19.289	1.415.519	256		
			Ličko-senjska	W3S1 - W3S2	8.069	592.142	544		
			Virovitičko-podravska	W3S1	15.466	1.134.969	544		
			Požeško-slavonska	W3S1	11.505	844.292	544		
			Brodsko-posavska	W3S1	22.794	1.672.733	544		
			Zadarska	W2S2 - W3S2	15.044	1.104.001	256		
			Osječko-baranjska	W3S2 - W3S1	43.485	3.191.137	544		
			Šibensko-kninska	W2S2	11.791	865.280	256		
			Vukovarsko-srijemska	W3S2 - W3S1	24.873	1.825.300	544		
			Splitsko-dalmatinska	W2S3 - W2S2	6.365	1.934.790	256		
			Istarska	W3S2	15.920	1.168.286	256		
			Dubrovačko-neretvanska	W2S2	10.775	790.721	256		
			Međimurska	W3S2	17.106	1.255.320	544		
			Grad Zagreb	W3S1	37.367	2.742.169	544		
			Undefined		3.838				
	MFH	497.141	Zagrebačka	W3S1	18.425	1.363.183	389		D
			Krapinsko-zagorska	W3S1	5.549	410.546	389		D

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			Sisačko-moslavačka	W3S1	12.962	959.000	389		
			Karlovačka	W3S1	13.652	1.010.050	389		
			Varaždinska	W3S1	10.305	762.421	389		
			Koprivničko-križevačka	W3S1	4.344	321.393	389		
			Bjelovarsko-bilogorska	W3S1	5.960	440.954	389		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	60.465	4.473.534	176		
			Ličko-senjska	W3S1 - W3S2	4.445	328.866	389		
			Virovitičko-podravska	W3S1	2.966	219.441	389		
			Požeško-slavonska	W3S1	4.413	326.498	389		
			Brodsko-posavska	W3S1	7.909	585.151	389		
			Zadarska	W2S2 - W3S2	21.027	1.555.693	176		
			Osječko-baranjska	W3S2 - W3S1	24.196	1.790.153	389		
			Šibensko-kninska	W2S2	15.558	1.151.066	176		
			Vukovarsko-srijemska	W3S2 - W3S1	8.000	591.884	389		
			Splitsko-dalmatinska	W2S3 - W2S2	73.058	5.405.233	176		
			Istarska	W2S2 - W3S2	33.317	2.464.975	176		
			Dubrovačko-neretvanska	W2S2	16.032	1.186.136	176		
			Međimurska	W3S2	4.439	328.422	389		
			Grad Zagreb	W3S1	145.162	10.740.550	389		
			Undefined		4.957				
1981-2000	**SFH**	194.339	Zagrebačka	W3S1	18.772	1.558.289	467		D
			Krapinsko-zagorska	W3S1	7.588	629.890	467		F
			Sisačko-moslavačka	W3S1	12.145	1.008.173	467		
			Karlovačka	W3S1	7.729	641.595	467		
			Varaždinska	W3S1	10.103	838.664	467		
			Koprivničko-križevačka	W3S1	7.764	644.500	467		
			Bjelovarsko-bilogorska	W3S1	7.920	657.450	467		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	5.557	461.294	220		
			Ličko-senjska	W3S1 - W3S2	2.995	248.619	467		
			Virovitičko-podravska	W3S1	6.346	526.790	467		
			Požeško-slavonska	W3S1	5.613	465.943	467		
			Brodsko-posavska	W3S1	10.687	887.142	467		
			Zadarska	W2S2 - W3S2	6.868	570.122	220		
			Osječko-baranjska	W3S2 - W3S1	20.420	1.695.092	467		
			Šibensko-kninska	W2S2	4.023	333.955	220		
			Vukovarsko-srijemska	W3S2 - W3S1	15.553	1.161.409	467		
			Splitsko-dalmatinska	W2S3 - W2S2	9.400	780.307	220		
			Istarska	W2S2 - W3S2	6.360	527.952	220		
			Dubrovačko-neretvanska	W2S2	3.443	285.808	220		
			Međimurska	W3S2	8.021	665.834	467		

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			Grad Zagreb	W3S1	14.756	1.224.915	467		
			Undefined		2.276				
	MFH	190.947	Zagrebačka	W3S1	10.022	830.998	292		C
			Krapinsko-zagorska	W3S1	1.511	125.288	292		D
			Sisačko-moslavačka	W3S1	3.915	324.622	292		
			Karlovačka	W3S1	4.096	339.630	292		
			Varaždinska	W3S1	2.686	222.716	292		
			Koprivničko-križevačka	W3S1	1.849	153.314	292		
			Bjelovarsko-bilogorska	W3S1	2.132	176.780	292		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	18.289	1.516.476	132		
			Ličko-senjska	W3S1 - W3S2	1.661	137.726	292		
			Virovitičko-podravska	W3S1	1.134	94.028	292		
			Požeško-slavonska	W3S1	1.674	138.804	292		
			Brodsko-posavska	W3S1	4.030	334.157	292		
			Zadarska	W2S2 - W3S2	8.789	728.761	132		
			Osječko-baranjska	W3S2 - W3S1	7.947	658.944	292		
			Šibensko-kninska	W2S2	5.657	469.064	132		
			Vukovarsko-srijemska	W3S2 - W3S1	3.936	326.363	292		
			Splitsko-dalmatinska	W2S3 - W2S2	27.010	2.239.599	132		
			Istarska	W2S2 - W3S2	13.260	1.099.485	132		
			Dubrovačko-neretvanska	W2S2	6.316	523.706	132		
			Međimurska	W3S2	1.665	138.057	292		
			Grad Zagreb	W3S1	58.420	4.844.034	292		
			Undefined		4.948				
2001-2010	**SFH**	64.101	Zagrebačka	W3S1	6.171	480.124	227		D
			Krapinsko-zagorska	W3S1	1.514	117.794	227		E
			Sisačko-moslavačka	W3S1	3.147	244.847	227		
			Karlovačka	W3S1	1.687	131.254	227		
			Varaždinska	W3S1	2.624	204.156	227		
			Koprivničko-križevačka	W3S1	1.742	135.533	227		
			Bjelovarsko-bilogorska	W3S1	1.964	152.806	227		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	2.567	199.721	107		
			Ličko-senjska	W3S1 - W3S2	1.472	114.527	227		
			Virovitičko-podravska	W3S1	1.723	134.055	227		
			Požeško-slavonska	W3S1	2.044	159.030	227		
			Brodsko-posavska	W3S1	3.647	283.749	227		
			Zadarska	W2S2 - W3S2	3.105	241.579	107		
			Osječko-baranjska	W3S2 - W3S1	5.551	431.886	227		
			Šibensko-kninska	W2S2	1.535	119.428	107		
			Vukovarsko-srijemska	W3S2 - W3S1	4.926	343.424	227		
			Splitsko-dalmatinska	W2S3 - W2S2	3.366	261.886	107		

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			Istarska	W2S2 - W3S2	2.928	227.808	107		
			Dubrovačko-neretvanska	W2S2	977	76.014	107		
			Međimurska	W3S2	2.646	205.868	227		
			Grad Zagreb	W3S1	5.439	423.172	227		
			Undefined		3.326				
	MFH	88.109	Zagrebačka	W3S1	4.156	323.351	142		B
			Krapinsko-zagorska	W3S1	549	42.714	142		B
			Sisačko-moslavačka	W3S1	590	45.904	142		
			Karlovačka	W3S1	647	50.339	142		
			Varaždinska	W3S1	1.736	135.067	142		
			Koprivničko-križevačka	W3S1	682	53.062	142		
			Bjelovarsko-bilogorska	W3S1	690	53.684	142		
			Primorsko-goranska	W2S2 - W3S2 - W3S1	6.767	526.495	65		
			Ličko-senjska	W3S1 - W3S2	432	33.611	142		
			Virovitičko-podravska	W3S1	452	35.167	142		
			Požeško-slavonska	W3S1	318	24.741	142		
			Brodsko-posavska	W3S1	1.100	85.584	142		
			Zadarska	W2S2 - W3S2	3.558	276.824	65		
			Osječko-baranjska	W3S2 - W3S1	3.603	280.325	142		
			Šibensko-kninska	W2S2	1.485	115.538	65		
			Vukovarsko-srijemska	W3S2 - W3S1	1.039	80.838	142		
			Splitsko-dalmatinska	W2S3 - W2S2	10.337	804.253	65		
			Istarska	W2S2 - W3S2	5.065	394.074	65		
			Dubrovačko-neretvanska	W2S2	2.282	177.547	65		
			Međimurska	W3S2	603	46.915	142		
			Grad Zagreb	W3S1	37.102	2.884.170	142		
			Undefined		4.914				
Total		**1.495.187**			**1.495.187**				

Table 3.7: Buildings stock in Croatia, structure, primary energy consumption and CO_2 emissions

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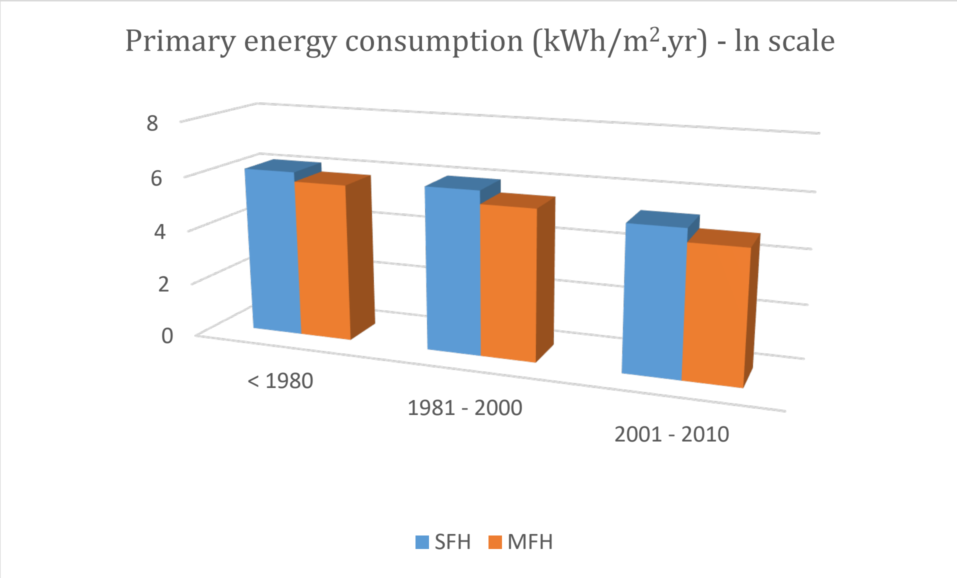
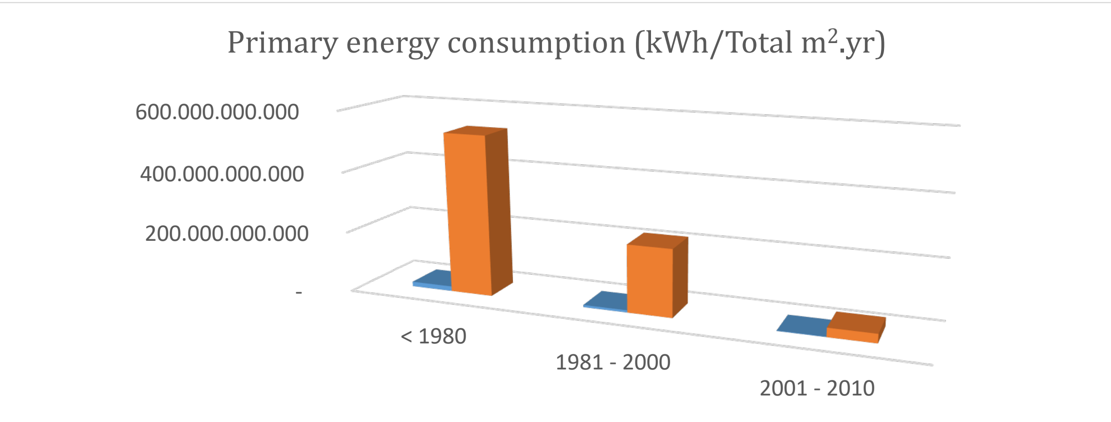


Figure 3.9 – Croatia: Buildings stock, Primary energy consumption per m² (kWh/m².yr)



	< 1980	1981 - 2000	2001 - 2010
SFH	15.352.845.091	7.349.749.560	1.178.487.094
MFH	529.628.113.236	220.088.401.371	29.287.320.800

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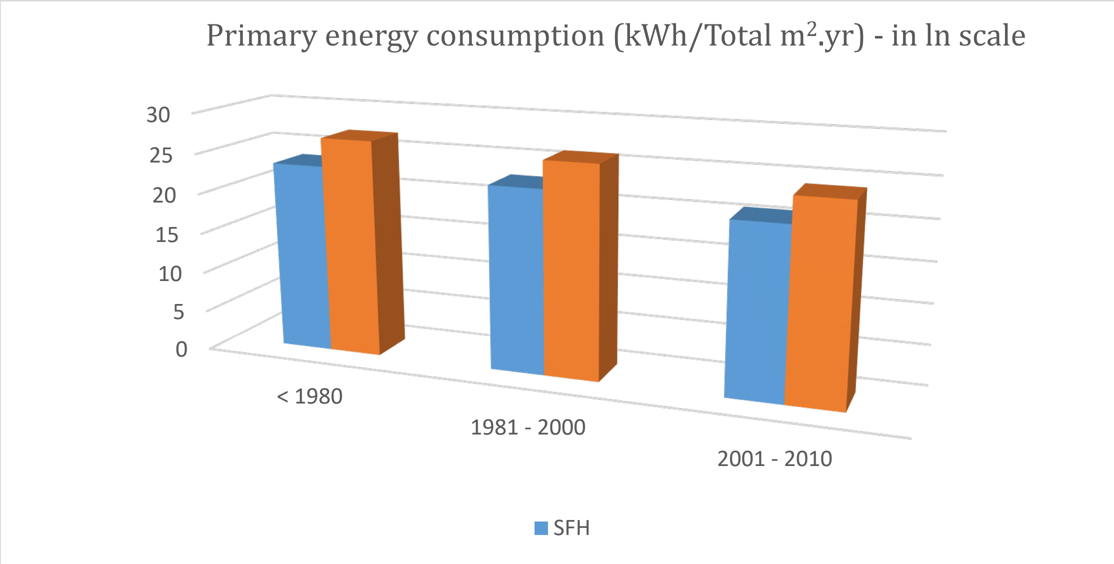

Figure 3.10 – Croatia: Buildings stock, Total Primary energy consumption (kWh/total m².yr)

3.4 Main characteristics and trend of the Buildings Stock in Italy

The results of the survey with reference to Italy are summarized in table 3.9 with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of primary energy consumption referred to the three construction periods chosen (<1980, 1981-2000, 2001-2010). Unfortunately data on CO_2 emission are not available.

Italy is divided into 20 principal regions and 2 autonomous provinces that correspond mainly to the climate zone colored in yellow, as shown in Table 3.8:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.8 : Italy, main climate zones (in yellow) resulting from the survey

Italy has a more varied climatic situation, even if with a prevalence of W2S2, and many regions have also internally very different climatic areas, from the mountain to the sea.

The total stock is of 12.398.634 buildings, built for about the 74% before of 1980 and only about 4% after 2001, then strongly old and with a prevalence of MFH in the first two periods, decreasing at about half of the stock built in the more recent period.

The average data related to the PEC (kWh/m².yr) of the buildings of the three period considered, are synthesized in fig 3.11 (expressed in natural logarithm, ln).

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The regions with the highest values of Primary energy consumption (for each m^2 every year) are those colder, with a prevalence of mountain areas, Valle D'Aosta, Trentino Alto Adige, Province Autonome of Trento and of Bolzano and Friuli-Venezia Giulia, in all the periods considered, both for SFH and MFH. (tab.3.9)

Primary energy consumption have dropped very much over time: buildings subsequent to 2001 have average values equal to approximately the 20% of those built before 1980% for the SFH (which have anyway values higher than the MFH in all the periods) and of about 25% for the MFH.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of buildingsconsidered are synthesized in fig. 3.12 (expressed in absolute values and then in natural logarithm).

The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding PEC (calculated as the average across all regions).

As we can see from the graphs, while both the trends relating to the SFH and to the MFH continue to decrease over time even if we consider the total m^2; consumption also shows that before 1980 the trend was to build large MFHs, a trend that has decreased more and more since the 1980s.

Period	Type	N° of RF	Region	Climate Zone	N°. of RF	Energy Certificate		
						Primary energy consumption ($kWh/m^2.yr$)	CO_2 emissions $kgCO_2/m^2.yr$	Letter energy efficiency
< 1980	**SFH**	3.120.104	Piemonte	W3S2-W3S1	265.358	610,11		G
			Valle d'Aosta	W3S1	10.401	743,75		G
			Liguria	W2S2-W3S2	77.644	493,96		G
			Lombardia	W3S1-W3S2	369.106	610,11		G
			Trentino Alto Adige	W2S2-W3S2	50.301	743,75		G
			Prov. Auton. Bolzano	W3S2	17.921	743,75		G
			Prov.Auton. Trento	W2S2-W3S2	32.380	743,75		G
			Veneto	W2S2	257.958	610,11		G
			Friuli-Venezia Giulia	W2S2	77.165	743,75		G
			Emilia-Romagna	W2S2-W3S2	212.254	610,11		G
			Toscana	W2S2-W4S0	204.289	493,96		G
			Umbria	W2S2	50.037	610,11		G
			Marche	W2S2	82.559	493,96		G
			Lazio	W2S2-W2S3	192.238	493,96		G
			Abruzzo	W2S2	91.294	493,96		G
			Molise	W2S2	29.856	610,11		G
			Campania	W2S2-W1S2	207.488	493,96		G
			Puglia	W1S3-W2S2-W2S3	233.451	493,96		G
			Basilicata	W2S2	39.106	493,96		G
			Calabria	W2S2-W1S3	155.462	493,96		G

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			Sicilia	W1S3	354.179	373,57		G
			Sardegna	W2S2-W1S3	109.655	373,57		G
	MFH	6.056.672	Piemonte	W3S2-W3S1	515.107	385,38		G
			Valle d'Aosta	W3S1	20.190	460,38		G
			Liguria	W2S2-W3S2	150.721	321,73		G
			Lombardia	W3S1-W3S2	716.499	385,38		G
			Trentino Alto Adige	W2S2-W3S2	97.643	460,38		G
			Prov. Auton. Bolzano	W3S2	34.787	460,38		G
			Prov.Auton. Trento	W2S2-W3S2	62.856	460,38		G
			Veneto	W2S2	500.743	385,38		G
			Friuli-Venezia Giulia	W2S2	149.790	460,38		G
			Emilia-Romagna	W2S2-W3S2	412.023	385,38		G
			Toscana	W2S2-W4S0	396.561	321,73		G
			Umbria	W2S2	97.130	385,38		G
			Marche	W2S2	160.263	321,73		G
			Lazio	W2S2-W2S3	373.167	321,73		G
			Abruzzo	W2S2	177.219	321,73		G
			Molise	W2S2	57.955	385,38		G
			Campania	W2S2-W1S2	402.771	321,73		G
			Puglia	W1S3-W2S2-W2S3	453.171	321,73		G
			Basilicata	W2S2	75.913	321,73		G
			Calabria	W2S2-W1S3	301.780	321,73		G
			Sicilia	W1S3	687.524	223,31		G
			Sardegna	W2S2-W1S3	212.860	223,31		G
1981-2000	**SFH**	546.161	Piemonte	W3S2-W3S1	24.922	262,29		F
			Valle d'Aosta	W3S1	2.070	294,43		F
			Liguria	W2S2-W3S2	5.634	270,00		F
			Lombardia	W3S1-W3S2	62.665	262,29		F
			Trentino Alto Adige	W2S2-W3S2	9.391	294,43		F
			Prov. Auton. Bolzano	W3S2	4.706	294,43		F
			Prov.Auton. Trento	W2S2-W3S2	4.685	294,43		F
			Veneto	W2S2	47.509	262,29		F
			Friuli-Venezia Giulia	W2S2	12.896	294,43		F
			Emilia-Romagna	W2S2-W3S2	30.297	262,29		F
			Toscana	W2S2-W4S0	20.653	270,00		F
			Umbria	W2S2	8.074	262,29		F
			Marche	W2S2	11.067	270,00		F
			Lazio	W2S2-W2S3	41.249	270,00		F
			Abruzzo	W2S2	13.125	270,00		F
			Molise	W2S2	3.431	262,29		F
			Campania	W2S2-W1S2	54.547	270,00		F

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			Puglia	W1S3-W2S2-W2S3	48.613	270,00		F
			Basilicata	W2S2	8.240	270,00		F
			Calabria	W2S2-W1S3	27.900	270,00		F
			Sicilia	W1S3	72.349	168,43		F
			Sardegna	W2S2-W1S3	32.137	168,43		F
	MFH	1.828.454	Piemonte	W3S2-W3S1	83.434	176,36		E
			Valle d'Aosta	W3S1	6.932	197,57		E
			Liguria	W2S2-W3S2	18.863	171,64		E
			Lombardia	W3S1-W3S2	209.790	176,36		E
			Trentino Alto Adige	W2S2-W3S2	31.440	197,57		E
			Prov. Auton. Bolzano	W3S2	15.756	197,57		E
			Prov.Auton. Trento	W2S2-W3S2	15.684	197,57		E
			Veneto	W2S2	159.053	176,36		E
			Friuli-Venezia Giulia	W2S2	43.172	197,57		E
			Emilia-Romagna	W2S2-W3S2	101.431	176,36		E
			Toscana	W2S2-W4S0	69.142	171,64		E
			Umbria	W2S2	27.031	176,36		E
			Marche	W2S2	37.051	171,64		E
			Lazio	W2S2-W2S3	138.094	171,64		E
			Abruzzo	W2S2	43.939	171,64		E
			Molise	W2S2	11.487	176,36		E
			Campania	W2S2-W1S2	182.616	171,64		E
			Puglia	W1S3-W2S2-W2S3	162.747	171,64		E
			Basilicata	W2S2	27.588	171,64		E
			Calabria	W2S2-W1S3	93.404	171,64		E
			Sicilia	W1S3	242.214	108,86		E
			Sardegna	W2S2-W1S3	107.587	108,86		E
2001-2010	**SFH**	440.567	Piemonte	W3S2-W3S1	29.052	136,71		C
			Valle d'Aosta	W3S1	1.886	152,86		C
			Liguria	W2S2-W3S2	5.515	116,29		C
			Lombardia	W3S1-W3S2	67.902	136,71		C
			Trentino Alto Adige	W2S2-W3S2	11.524	152,86		C
			Prov. Auton. Bolzano	W3S2	6.486	152,86		C
			Prov.Auton. Trento	W2S2-W3S2	5.037	152,86		C
			Veneto	W2S2	47.847	136,71		C
			Friuli-Venezia Giulia	W2S2	12.137	152,86		C
			Emilia-Romagna	W2S2-W3S2	32.138	136,71		C
			Toscana	W2S2-W4S0	22.284	116,29		C
			Umbria	W2S2	9.187	136,71		C
			Marche	W2S2	10.756	116,29		C

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			Lazio	W2S2-W2S3	29.360	116,29		C
			Abruzzo	W2S2	11.916	116,29		C
			Molise	W2S2	2.384	136,71		C
			Campania	W2S2-W1S2	23.341	116,29		C
			Puglia	W1S3-W2S2-W2S3	25.644	116,29		C
			Basilicata	W2S2	4.778	116,29		C
			Calabria	W2S2-W1S3	16.277	116,29		C
			Sicilia	W1S3	39.080	83,29		C
			Sardegna	W2S2-W1S3	26.037	83,29		C
	MFH	406.677	Piemonte	W3S2-W3S1	26.817	91,67		B
			Valle d'Aosta	W3S1	1.741	100,10		B
			Liguria	W2S2-W3S2	5.091	76,48		B
			Lombardia	W3S1-W3S2	62.678	91,67		B
			Trentino Alto Adige	W2S2-W3S2	10.637	100,10		B
			Prov. Auton. Bolzano	W3S2	5.988	100,10		B
			Prov.Auton. Trento	W2S2-W3S2	4.650	100,10		B
			Veneto	W2S2	44.166	91,67		B
			Friuli-Venezia Giulia	W2S2	11.203	100,10		B
			Emilia-Romagna	W2S2-W3S2	29.666	91,67		B
			Toscana	W2S2-W4S0	20.570	76,48		B
			Umbria	W2S2	8.480	91,67		B
			Marche	W2S2	9.928	76,48		B
			Lazio	W2S2-W2S3	27.102	76,48		B
			Abruzzo	W2S2	11.000	76,48		B
			Molise	W2S2	2.201	91,67		B
			Campania	W2S2-W1S2	21.545	76,48		B
			Puglia	W1S3-W2S2-W2S3	23.672	76,48		B
			Basilicata	W2S2	4.410	76,48		B
			Calabria	W2S2-W1S3	15.024	76,48		B
			Sicilia	W1S3	36.073	55,24		C
			Sardegna	W2S2-W1S3	24.034	55,24		C
Total ITALY		**12.398.634**			**12.398.634**			

Table 3.9 - Buildings stock in Italy, structure, primary energy consumption and CO_2 emissions

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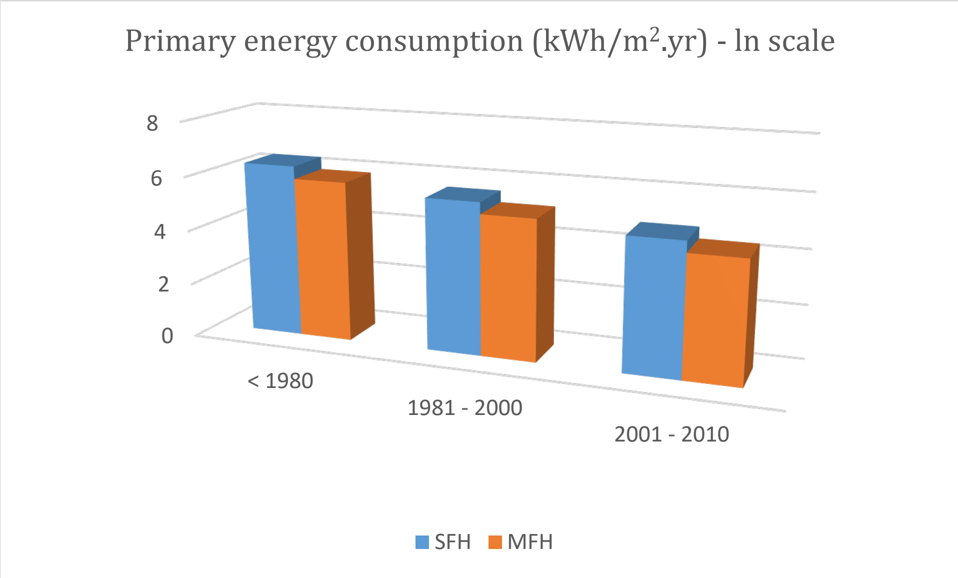

Figure 3.11– Italy: Buildings stock, Primary energy consumption per m² (kWh/m².yr)

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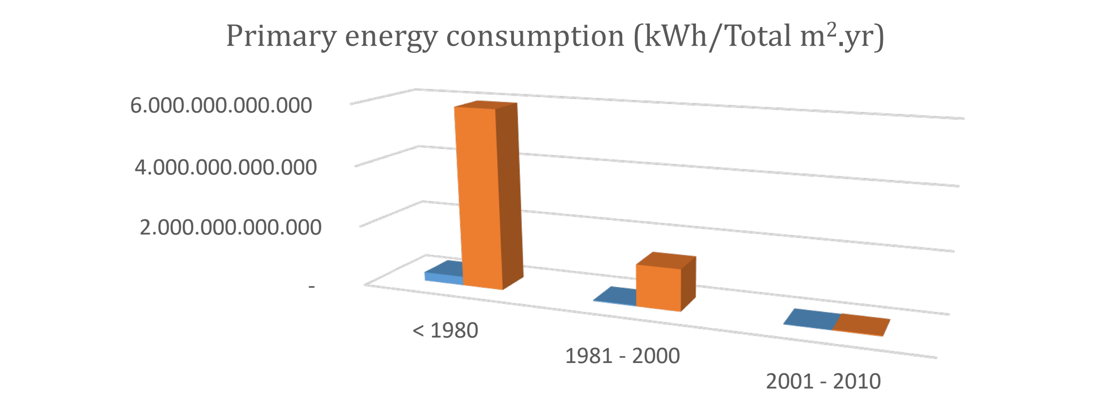

	< 1980	1981 - 2000	2001 - 2010
SFH	288.493.884.770	30.592.375.368	10.757.064.035
MFH	5.914.100.795.858	1.359.813.923.767	28.030.687.030

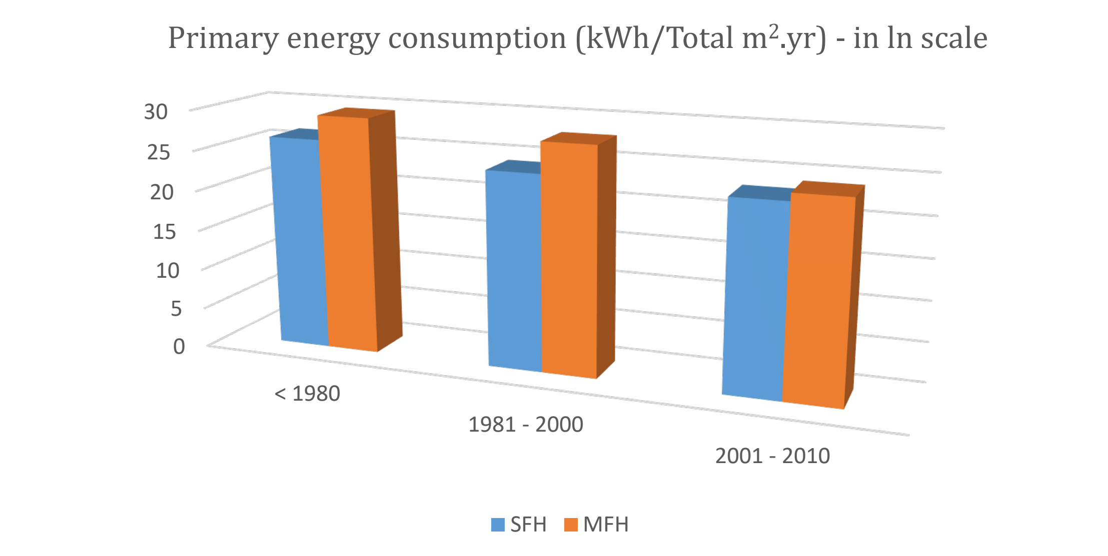

Figure 3.12 – Italy: Building stock, Total Primary energy consumption (kWh/total m².yr)

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3.5 Main characteristics and trend of the Buildings Stock in Cyprus

The results of the survey with reference to Cyprus are summarized in table 3.11, with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of primary energy consumption and CO_2 emission referred to the three construction periods chosen (<1980, 1981-2000, 2001-2010).

Cyprus is divided into 5 principal regions that correspond mainly to the climate zone colored in yellow, as shown in table 3.10:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.10: Cyprus, main climate zones (in yellow) resulting from the survey

Cyprus, being a rather little island, has a more uniform climatic situation, with only 2 warm climatic zones W0S3 and W0S4. The winter is always pleasant, but the summer could be very hot.

The total stock is of 331.324 buildings and, differently from other countries, was built for only the 21% before of 1980 and about 40% each in the other two more recent periods, then rather new and with a strong prevalence (about 73%) of SFH in the first period, decreases over the year at the 51% after 2001.

The average data related to the PEC (kWh/m^2.yr) of the buildings of the three period of time considered, are synthesized in fig 3.13 (expressed in natural logarithm, ln); which related to the CO_2 emissions (kgCO_2/m^2.yr) are shown in fig. 3.14.

The region with the highest PEC value and CO_2 emissions (for each m^2 every year) is Limassol in the last period considered, both for SFH and MFH (tab.3.11), only for the SFH in the second one and only for the CO_2 emissions of the SFH in the first one. Larnaca presents the highest values for the MFH built before 1980, while Phaphos for which built in the second period. In any case, being Cyprus a small and homogeneous countries as climatic zones, the values do not differ much from one region to another.

Both PEC and CO_2 emissions have dropped over time but less than in the other countries and with a spike in growth in the second period for the MFH (higher for the CO_2 emissions); there is also greater variability between regions in the decreasing trend of values, compared to previous countries.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of of building of the periodsof time considered, are synthesized in fig. 3.15 (expressed in absolute values and then in natural logarithm); which related to the total CO_2 emissions (kgCO_2/total m^2.yr), are shown in fig.3.16.

The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding PEC and CO_2 values (calculated as the average across all regions).

As we can see from the graphs, if we consider the total m^2 of the stock of buildings all the trends tend to rise between the first and second periods, and then fall again in the last one. This, as we have seen before,

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does not depend on the fact that consumption and emissions increased at a unitary level, but because the stock of buildings has increased significantly over time, especially between the '80 and 2000.

Period	Type	N°. of RF	Region	Climate Zone	N. of RF [1],[2],[3]	Average m² [1],[2],[3]	Energy Certificate		
							Primary energy consumption (kWh/m².yr) [3],[4]	CO_2 emissions (kgCO_2/m².yr)	Letter energy efficiency
< 1980	**SFH**	50.416	**Larnaca**	**W0S3**	10.083	149,4	305,2	106,8	G
			Limassol	**W0S4**	12.604	154,1	411,3	135,3	G
			Nicosia	W0S3	20.671	135,6	391,1	107,4	G
			Paphos	W0S4	4.537	180,6	450,5	123,1	G
			Famagusta	W0S3	2.521	221,8	317,7	106,1	G
								0,0	
	MFH	18.647	**Larnaca**	**W0S3**	3.729	121,0	484,0	160,8	G
			Limassol	**W0S4**	4.662	116,0	364,5	121,1	G
			Nicosia	W0S3	7.645	113,3	367,6	100,9	G
			Paphos	W0S4	1.678	88,6	478,3	157,3	G
			Famagusta	W0S3	932	91,0	403,1	130,4	G
								0,0	
1981-2000	**SFH**	88.468	**Larnaca**	**W0S3**	15.841	151,2	289,5	103,9	F
			Limassol	**W0S4**	24.215	130,4	384,9	128,5	F
			Nicosia	W0S3	29.615	153,4	366,5	103,0	F
			Paphos	W0S4	11.302	176,9	321,9	109,1	F
			Famagusta	W0S3	7.495	102,8	328,2	90,3	F
								0,0	
	MFH	43.574	**Larnaca**	**W0S3**	7.803	121,5	392,5	130,4	F
			Limassol	**W0S4**	11.927	99,8	313,5	110,7	F
			Nicosia	W0S3	14.586	70,3	368,8	122,5	F
			Paphos	W0S4	5.566	92,6	401,3	134,6	F
			Famagusta	W0S3	3.692	88,7	386,5	131,4	F
2001-2010	**SFH**	65.332	**Larnaca**	**W0S3**	**11.356**	142,8	185,92	60,11	D
			Limassol	**W0S4**	**12.819**	146,6	255,68	82,67	D
			Nicosia	W0S3	18.560	151,6	240,93	77,90	D
			Paphos	W0S4	16.118	187,7	141,11	45,63	D
			Famagusta	W0S3	6.480	115,0	191,24	61,84	D
	MFH	64.887	**Larnaca**	**W0S3**	**10.911**	130,0	207,47	67,08	D
			Limassol	**W0S4**	**12.819**	109,3	284,91	92,12	D
			Nicosia	W0S3	18.560	115,0	227,47	73,55	D
			Paphos	W0S4	16.118	72,3	225,40	72,88	D
			Famagusta	W0S3	6.480	76,7	218,29	70,58	D

[1] https://episcope.eu/building-typology/country/cy/

[2] http://www.cea.org.cy/TOPICS/Buildings/BuildingstypologyCyprus.pdf

[3] Cyprus Statistical Service (CYSTAT) Archives - Table 15(a) Dwellings Completed in the Private Sector by District and Type

[4] http://tool.european-calculator.eu/app/buildings/building-types-area/?levers=1111122ffl112112221211ffffffffff11f411111221111211l2122212&other=1111122ffl112112221211ffffffffff11f4111112211 11211l2122212&country=CY

Table 3.11 - Buildings stock in Cyprus, structure, primary energy consumption and CO_2 emissions

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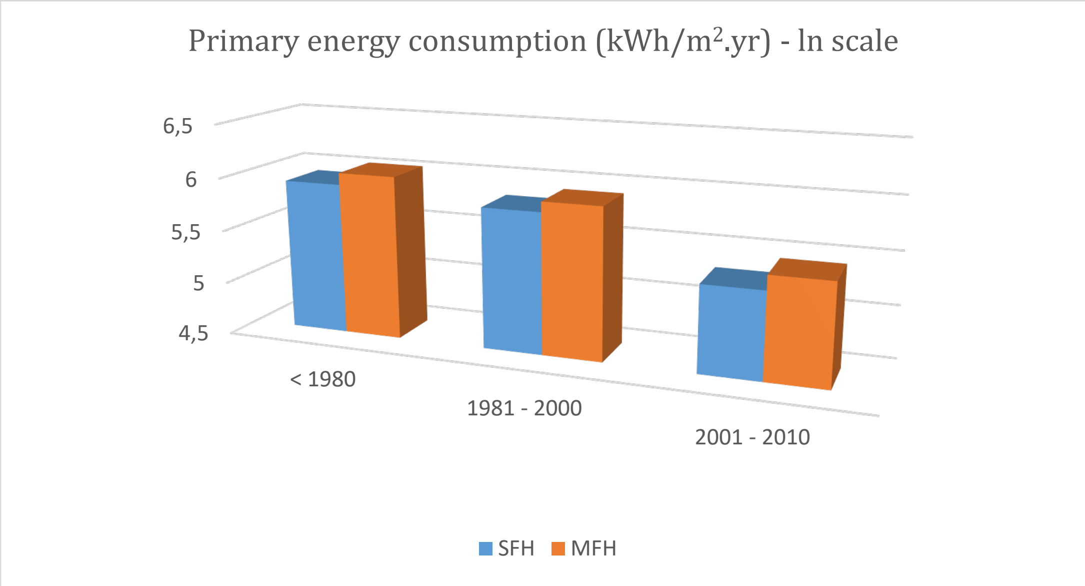

Figure 3.13 – Cyprus: Building stock, Primary energy consumption per m² (kWh/m².yr)

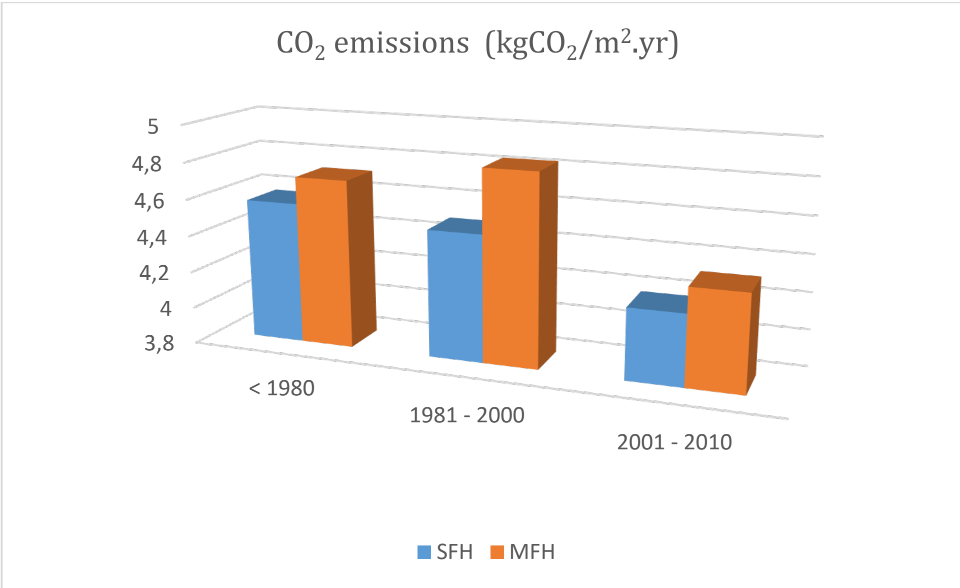

Figure 3.14 – Cyprus: buildings stock, CO_2 emissions per m² (kgCO₂/ m².yr)

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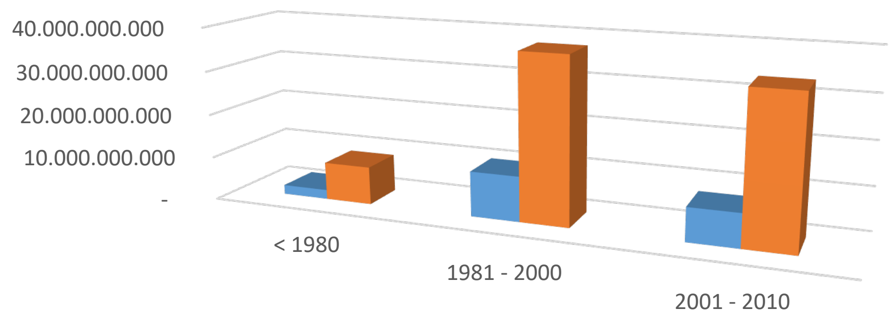
Primary energy consumption (kWh/Total m²/yr)



	< 1980	1981 - 2000	2001 - 2010
SFH	2.118.368.889	10.292.770.596	7.638.276.997
MFH	8.683.069.878	37.658.238.556	33.521.151.976

Primary energy consumption (kWh/Total m².yr)- in ln scale

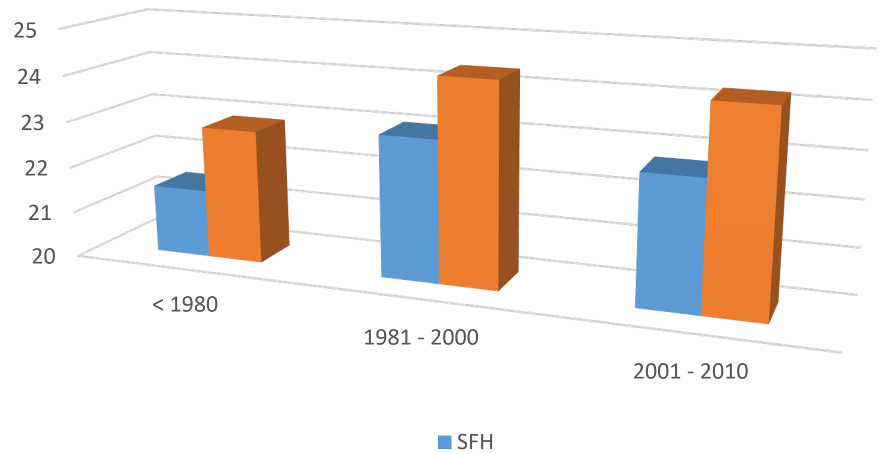


Figure 3.15 – Cyprus: Buildings stock, Total Primary energy consumption (kWh/total m².yr)

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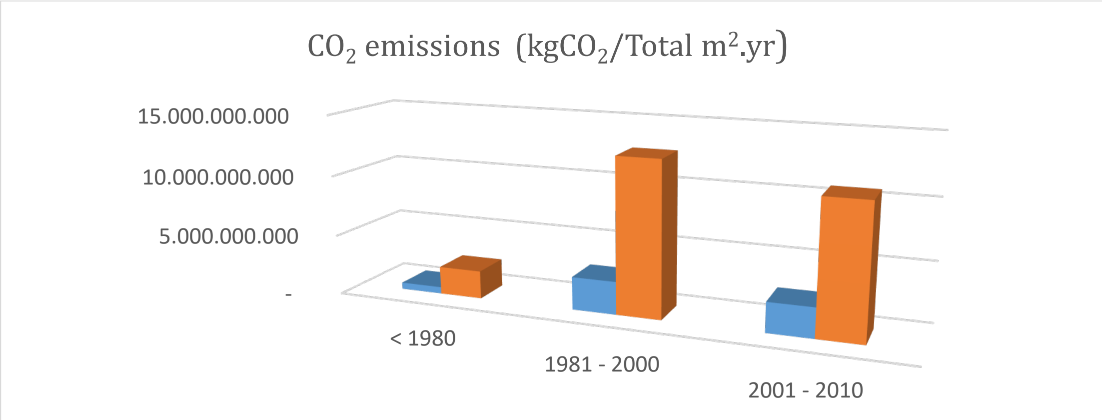

	< 1980	1981 - 2000	2001 - 2010
SFH	544.562.088	2.713.195.716	2.469.709.308
MFH	2.313.233.863	12.729.648.420	10.838.504.688

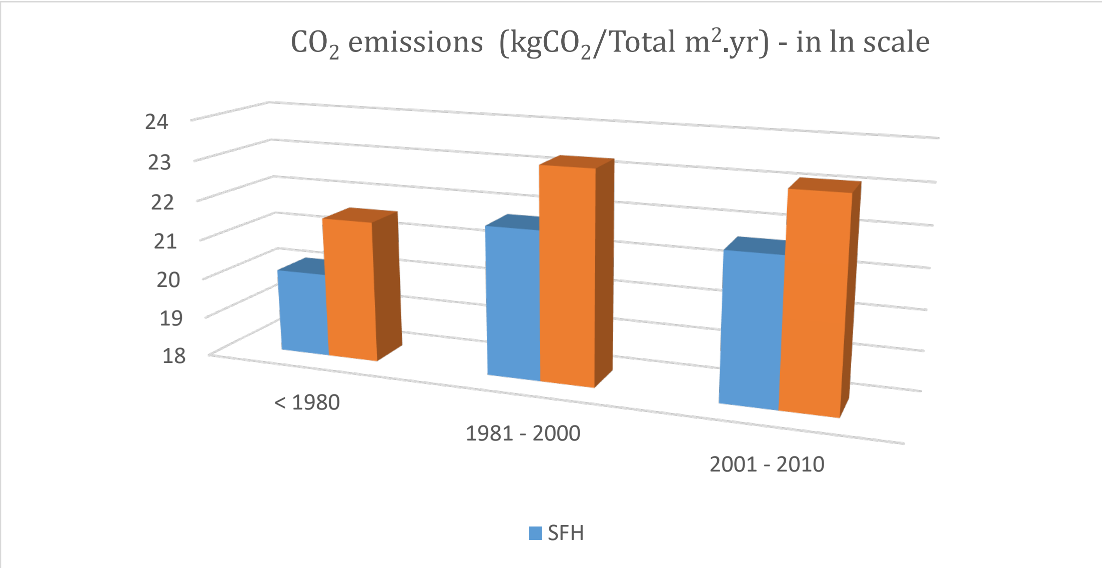

Figure 3.16 – Cyprus: buildings stock total CO_2 emissions (kgCO_2/Total m^2.yr)

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3.6 Main characteristics and trend of the Buildings Stock in France

The results of the survey with reference to Slovenia are summarized in table 3.13 with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of primary energy consumption and Co_2 emission, referred to the three construction periods chosen (<1980, 1981-2000, 2001-2010).

France is divided into 5 main climate zone coloredin yellow, as shown in table 3.12:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.12 : France, main climate zones (in yellow) resulting from the survey

France has a rather varied climatic situation from the North to the South, but never too hot (not S3 or S4), also along the south cost. The winters are almost cold (W2 and W3) and the summer pleasant.

The total stock is of 28.715.069 dwellings, built for about the 64% before of 1980 and only about 15% after 2001, then rather old and with a good prevalence (about 67%) of SFH (tab.3.13).

The average data related to the PEC (kWh/m^2.yr) of the buildings of the three period considered, are synthesized in fig 3.17 (expressed in natural logarithm, ln); which related to the CO_2 emissions (kgCO_2/m^2.yr) are shown in fig. 3.18.

Both PEC and CO_2 emissions have dropped considerably over time, especially the second one: buildings subsequent to 2001 have average values equal to approximately 16% and 4% respectively of those built before 1980 for the SFH and of 30% for the MFH.

The average data related to the PEC (kWh/total m^2.yr) for the total stock ofbuilding of the three periods are synthesized in fig. 3.19 (expressed in absolute values and then in natural logarithm); which related to the total CO_2 emissions (kgCO_2/total m^2.yr), are shown in fig.3.20.

The graphs were obtained by multiplying the number of Dwellings per period of each type of building in each period considered by the corresponding PEC and CO_2 values.

As we can see from the graphs, all the trends continue to decrease over time even if we consider the total m^2 of the dwelling, particularly from 1981.

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Period	Type	Surface of dwellings per period	Number of dwellings per period	Region	Climate Zone	Energy Certificate		
						Primary energy consumption (kWh/m²).yr)	CO_2 emissions ($kgCO_2/m^2.yr$)	Letter energy efficiency
< 1980	SFH	950.747.638	10.287.674		W2S0 W2S1 W2S2 W3S0 W3S1	600	178	G
	MFH	525.444.433	8.406.136		W2S0 W2S1 W2S2 W3S0 W3S1	283	73	E
1981-2000	SFH	410.792.220	3.569.796		W2S0 W2S1 W2S2 W3S0 W3S1	202	8	D
	MFH	148.570.487	2.230.001		W2S0 W2S1 W2S2 W3S0 W3S1	128	33	C
2001-2010	SFH	313.431.843	2.417.915		W2S0 W2S1 W2S2 W3S0 W3S1	96	7	C
	MFH	130.124.059	1.803.547		W2S0 W2S1 W2S2 W3S0 W3S1	86	22	B
		2.479.110.680	**28.715.069**					

Table 3.13: Buildings stock in France, structure, primary energy consumption and CO_2 emissions

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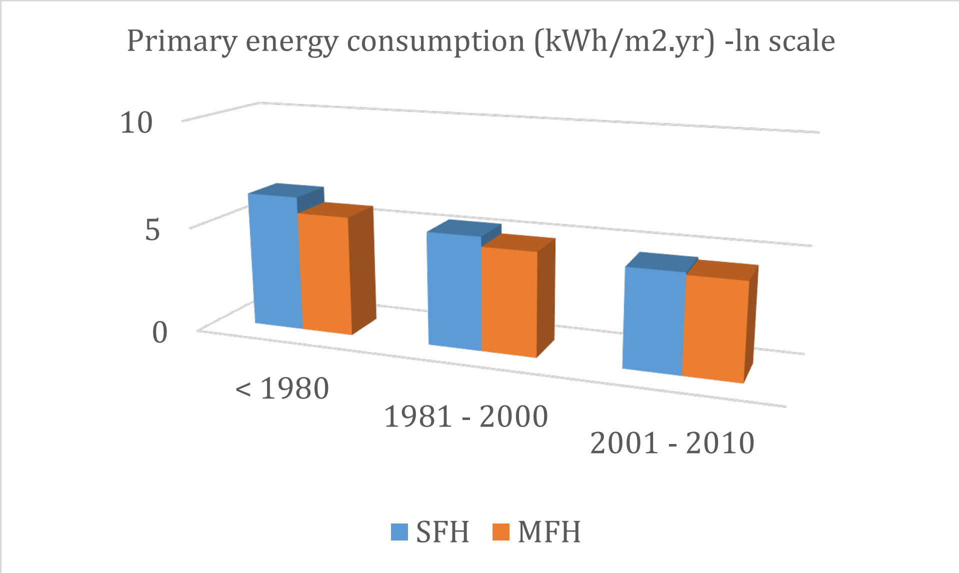

Figure 3,17 – France: Buildings stock, Primary energy consumption per m² (kWh/m².yr)

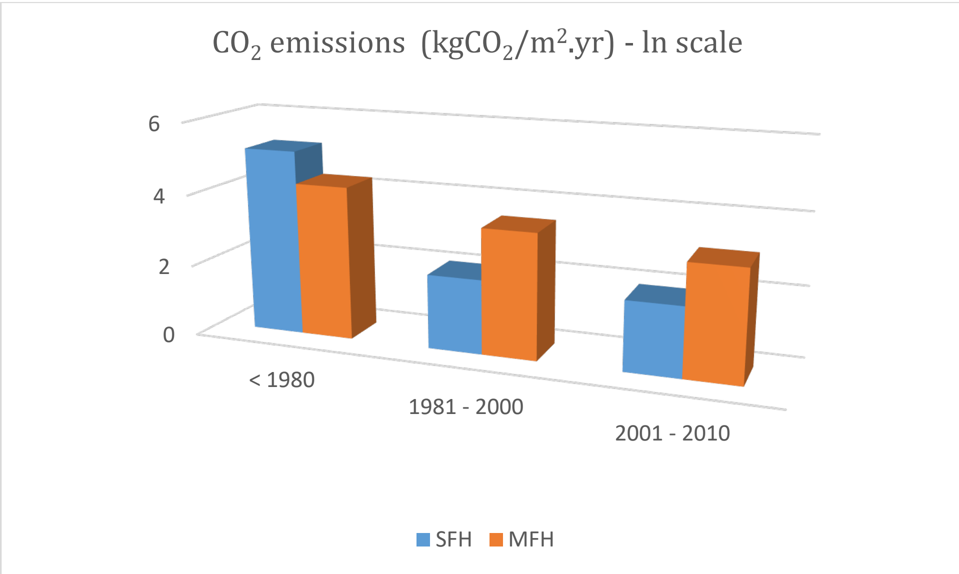

Figure 3.18 –France: buildings stock, CO_2 emissions per m² (kgCO_2/ m².yr)

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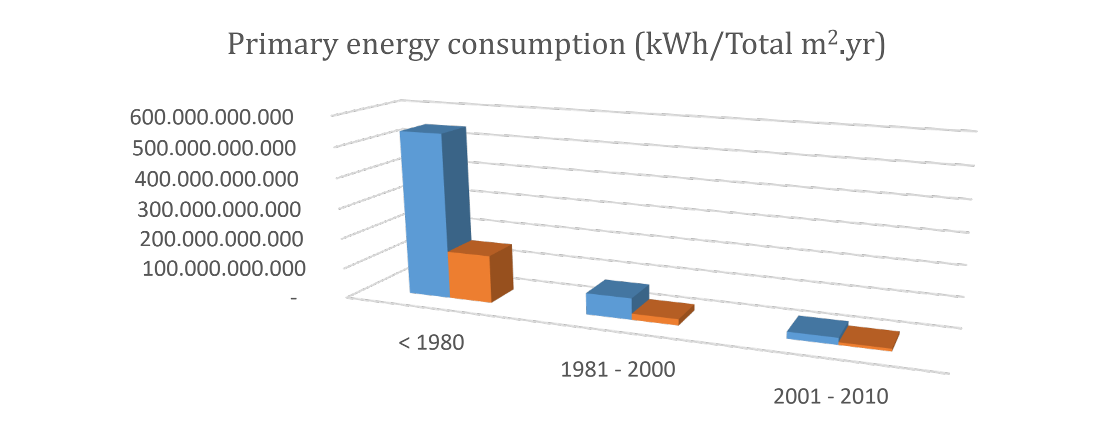

	< 1980	1981 - 2000	2001 - 2010
SFH	543.189.187.200	69.946.582.824	22.051.384.800
MFH	157.009.808.208	20.220.744.140	8.408.136.114

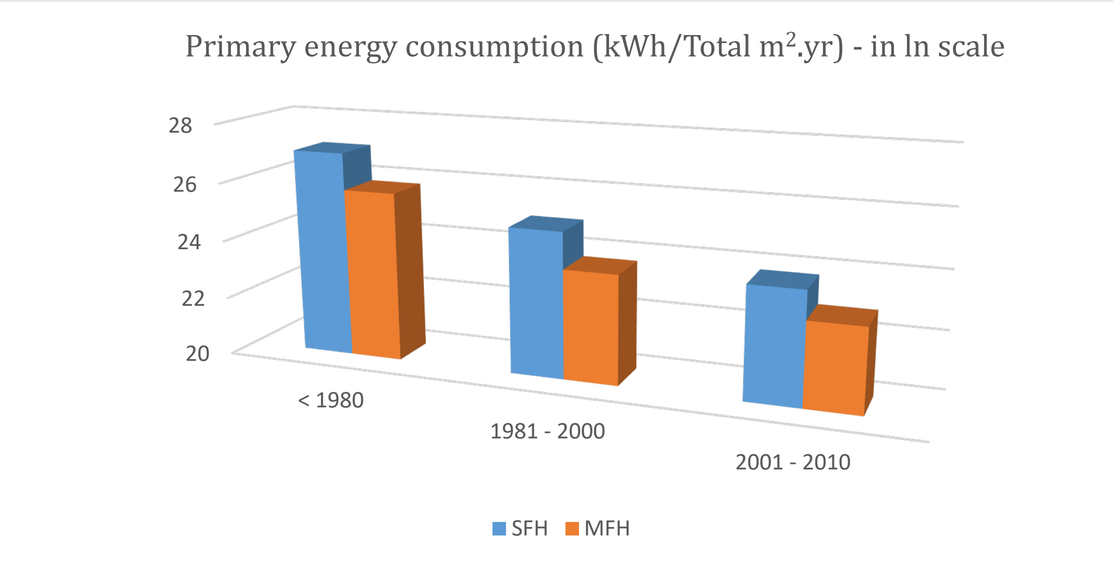

Figure 3.19 – France: Buildings stock, Total Primary energy consumption (kWh/total m^2.yr)

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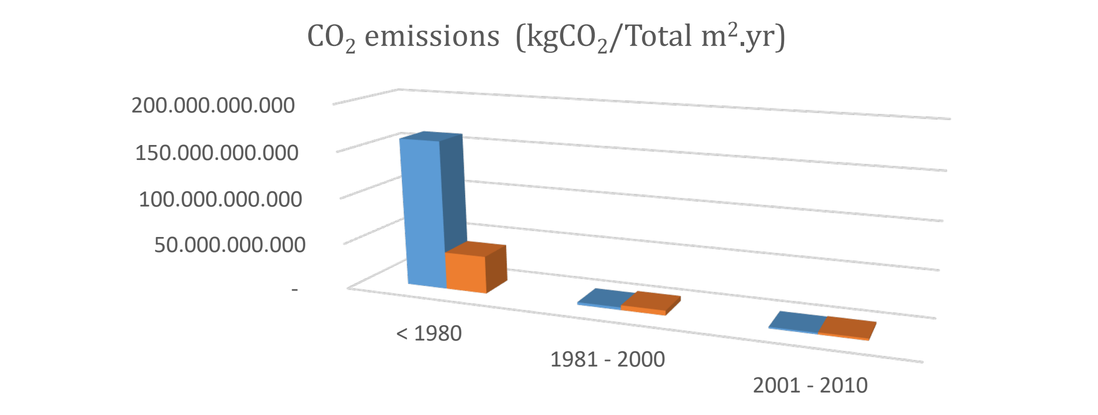

	< 1980	1981 - 2000	2001 - 2010
SFH	161.146.125.536	2.770.161.696	1.607.913.475
MFH	40.500.763.248	5.213.160.599	2.150.918.541

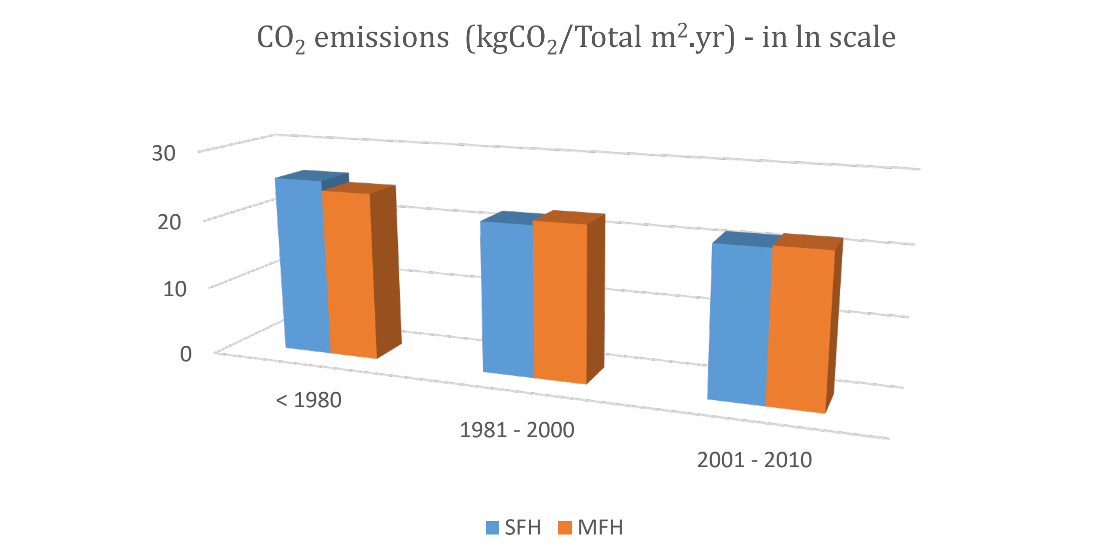

Figure 3.20 – France: buildings stock total CO_2 emissions (kgCO_2/Total m^2.yr)

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3.7 Main characteristics and trend of the Buildings Stock in Greece

The results of the survey carried out in Greece are summarized in table 3.15, with the main answers related to the stock of RBs in each region /climate zone and its characteristics in terms of PEC and CO_2 emission referred to the three construction periods chosen (<1980, 1981-2000, 2001-2010).

Greece is divided into 5 principal regions that correspond to the climate zone coloured in yellow, shown in table 3.14:

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

Table 3.14: Greece, main climate zones (in yellow) resulting from the survey

With a strong prevalence of summer S3, the climate is somewhat very warm, with not very cold winters; the region of Heraklion (Crete) resulted to be hotter during the summer and that of Drama a little bit colder in the winter.

The total stock is of 6.754.424 buildings, built for about the 52% before of 1980 and about 20% after 2001, then rather old and with a prevalence (about 60%) of SFH (even if decreasing over the years).

The values of PEC and of CO_2 emissions are enough different between the various regions; however Drama presents always the highest PEC, followed by Thessaloniki and then Athens, because they are colder during the winter, especially the first one (tab.3.15).

About the CO_2 emissions, the situation is more various: the highest levels are registered always for the MFH of Thessaloniki, especially in last period, while in the other regions the values decrease also for the MFH. The SFH presents lower levels of CO_2 emissions already from the first period, with the best values in Kalamata.

The average data related to the PEC (kWh/m^2.yr) of the buildings of the three period considered, are synthesized in fig 3.21 (expressed in natural logarithm, ln); which related to the CO_2 emissions (kgCO_2/m^2.yr) are shown in fig. 3.22. As we can see from the graphs, while the trend relating to the PEC at the unit level is stable over the time, which of the CO_2 emissions starts decreasing from 1981 and still more from 2001, both for SFH and MFH.

The average data related to the PEC (kWh/total m^2.yr) for the total stock of building, are synthesized in fig. 3.23 (expressed in absolute values and then in natural logarithm); which related to the total CO_2 emissions (kgCO_2/total m^2.yr) are shown in fig.3.24. The graphs were obtained by multiplying the number of RBs of each type of building in each period considered by the corresponding PEC and CO_2 values (calculated as the average across all regions).

With reference to the total stock of building, the MFH trends are strongly decreased over the time, both for PEC and CO_2 emissions, for PEC much more after 2001. This depends mainly on the fact that over time the average size of the MFH buildings, after a little pick in the second period, has diminished

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considerably (both in terms of total floor area and of number of dwellings per building, tab.3.1); therefore, while almost stable the level of energy consumption and CO_2 emissions at the unit level, on the total m^2 the values dropped.

The SFH trend of the total stock of building decreases strongly for PEC in the second period, but rises again after 2001; the CO_2 emissions trend continues to decline even after 2001 but much less than before. This can depend mainly on the fact that in the last period the average size in m^2 of the SFH buildings, after a decrease in the second period, has started to grow again after 2001 (tab.3.1).

Period	Type	N°. of RF	Region (representative city)	Climate Zone	N°. of RF	Energy Certificate: Primary energy consumption (kWh/m^2.yr) (*)	Energy Certificate: CO_2 emissions ($kgCO_2/m^2.yr$)	Energy Certificate: Letter energy efficiency
< 1980	SFH	2.131.027	Kalamata	W0S3	79.328	256,03		
			Heraklion, Crete	W0S4	233.635	294,78	61,5	D
			Athens	W1S3	853.902	328,09	100,5	F
			Thessaloniki	W2S3	903.839	424,79	76,4	E
			Drama	W3S2	60.323	496,28	150,3	G
	MFH	1.387.544	Kalamata	W0S3	59.339	256,03		
			Heraklion, Crete	W0S4	54.347	294,78	333,9	C
			Athens	W1S3	852.814	328,09	59,1	D
			Thessaloniki	W2S3	400.809	424,79	95,8	F
			Drama	W3S2	20.234	496,28	101,5	F
1981-2000	SFH	960.157	Kalamata	W0S3	36.727	256,03		
			Heraklion, Crete	W0S4	107.406	294,78	96,0	G
			Athens	W1S3	396.693	328,09	29,9	B
			Thessaloniki	W2S3	385.216	424,79	74,9	F
			Drama	W3S2	34.115	496,28	68,9	E
	MFH	890.071	Kalamata	W0S3	34.391	256,03		
			Heraklion, Crete	W0S4	62.189	294,78	61,7	D
			Athens	W1S3	439.704	328,09	48,9	C
			Thessaloniki	W2S3	332.785	424,79	84,6	F
			Drama	W3S2	21.002	496,28	97,7	F
2001-2010	SFH	817.157	Kalamata	W0S3	75.001	256,03		
			Heraklion, Crete	W0S4	58.325	294,78	23,5	B
			Athens	W1S3	163.212	328,09	51,1	D
			Thessaloniki	W2S3	512.242	424,79	41,7	C
			Drama	W3S2	8.377	496,28	80,8	E
	MFH	568.468	Kalamata	W0S3	20.691	256,03		
			Heraklion, Crete	W0S4	30.918	294,78	29,8	B
			Athens	W1S3	276.089	328,09	37,0	C
			Thessaloniki	W2S3	226.011	424,79	66,2	C
			Drama	W3S2	14.759	496,28	44,0	D
Total		**6.754.424**			**6.754.424**			

(*) mean value for climatic zone

Table 3.15: Buildings stock in Greece, structure, primary energy consumption and CO_2 emissions

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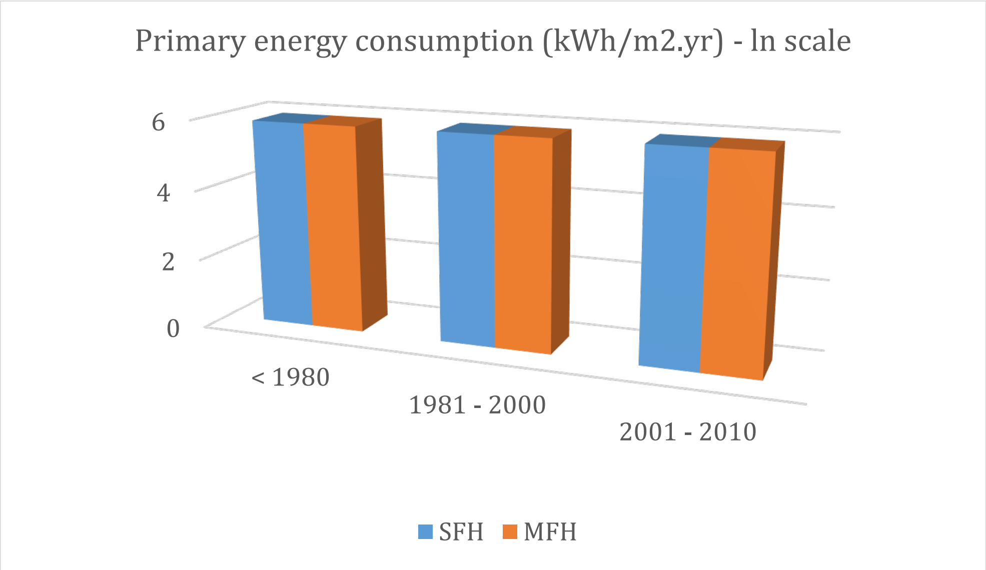

Figure 3.21 – Greece: Buildings stock, Primary energy consumption per m² (kWh/m².yr)

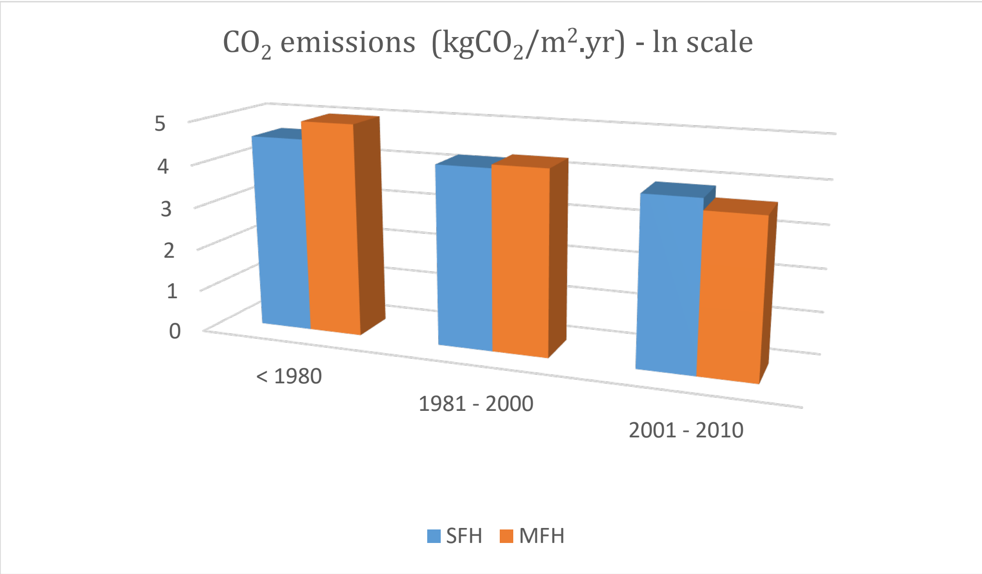

Figure 3.22 – Greece: buildings stock, CO_2 emissions per m² (kgCO_2/ m².yr)

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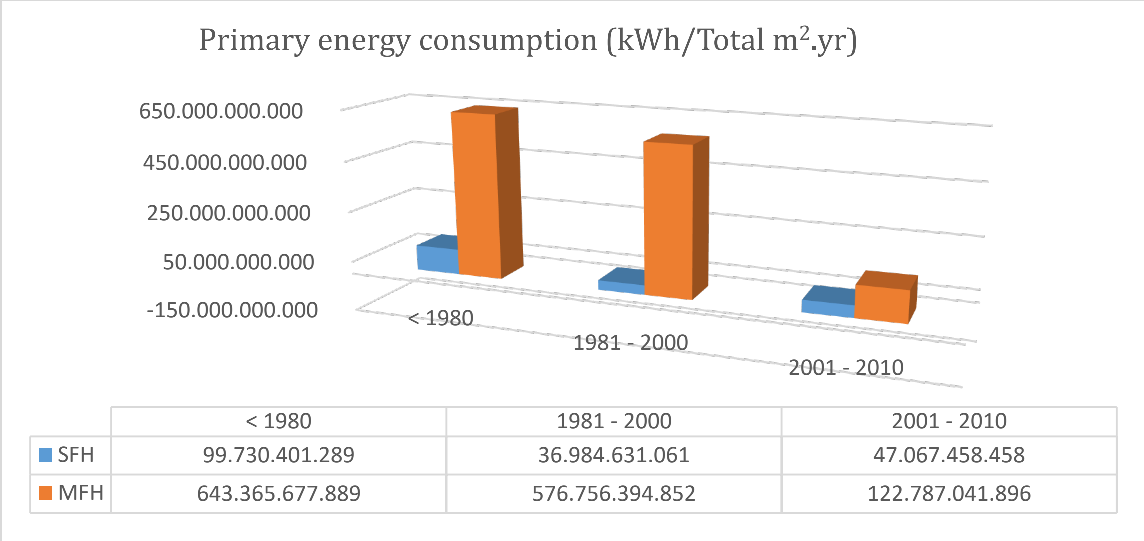

	< 1980	1981 - 2000	2001 - 2010
SFH	99.730.401.289	36.984.631.061	47.067.458.458
MFH	643.365.677.889	576.756.394.852	122.787.041.896

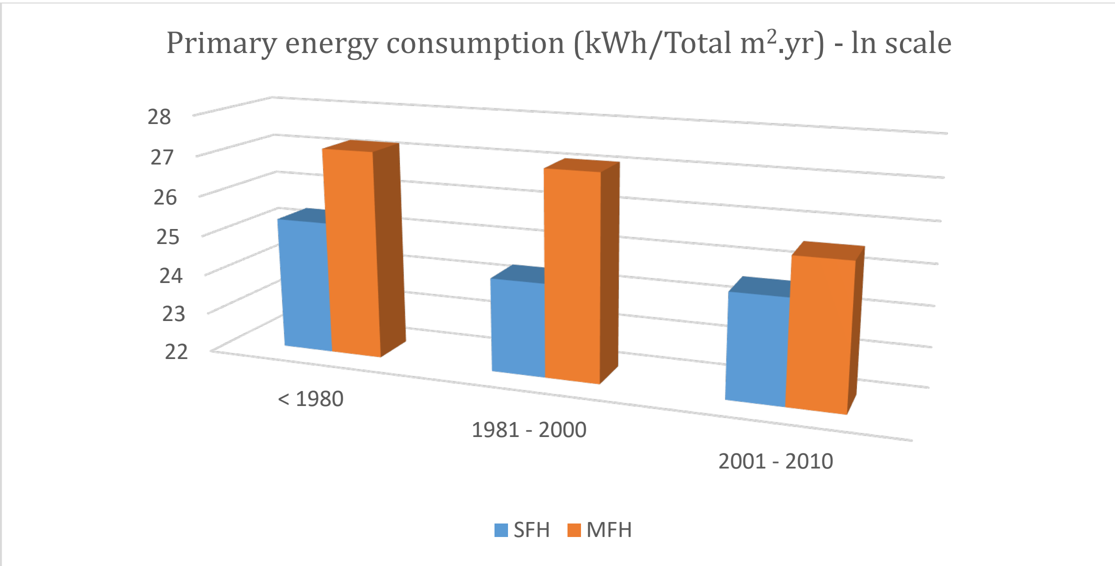

Figure 3.23 - Greece: Buildings stock, Total Primary energy consumption (kWh/total m^2.yr)

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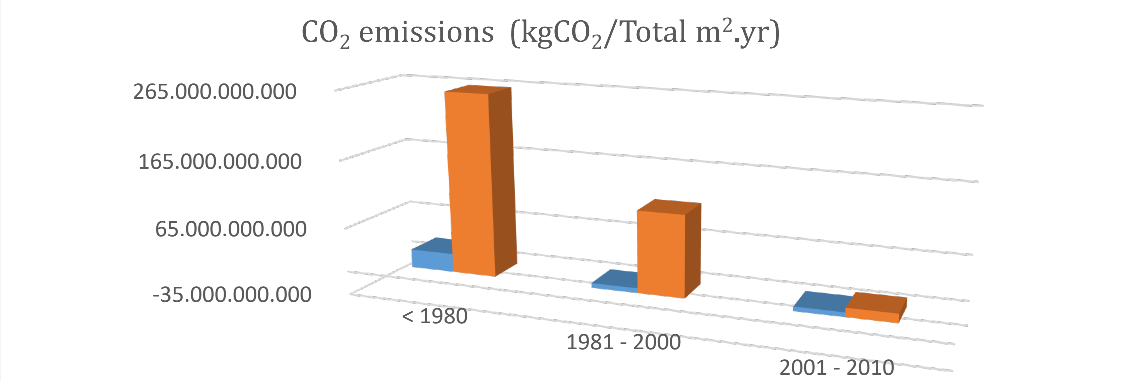

	< 1980	1981 - 2000	2001 - 2010
SFH	26.920.844.731	6.924.967.327	6.442.985.946
MFH	263.725.818.743	117.332.485.787	12.959.110.284

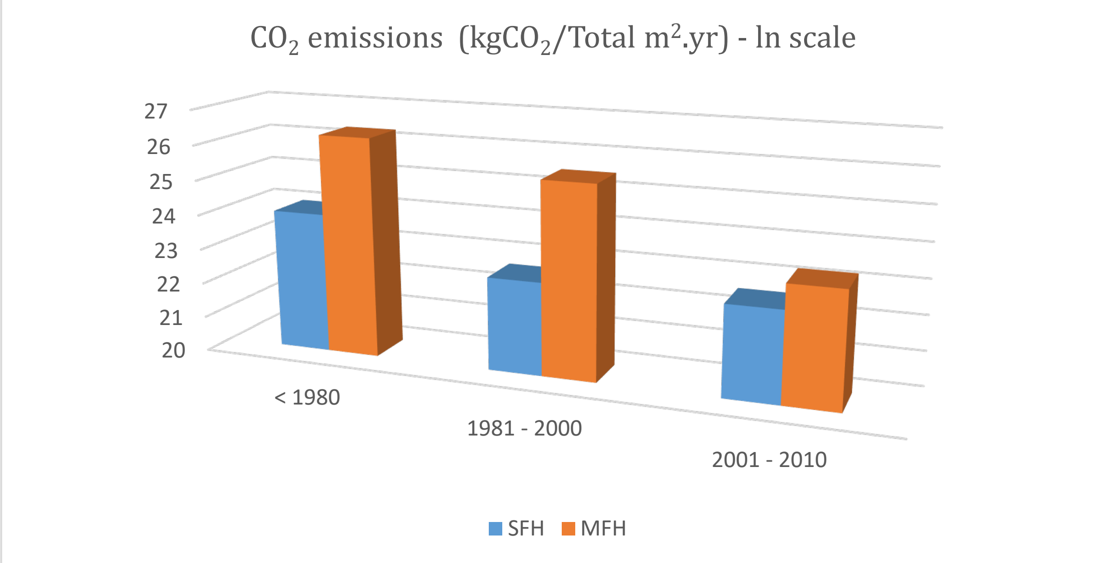

Figure 3.24 – Greece: buildings stock total CO_2 emissions ($kgCO_2$/Total m^2.yr)

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3.8 Primary energy consumption and CO_2 emissions trends: a comparison among the Happen Countries

In the previous paragraphs of this chapter we presented the stock of existing residential buildings resulting from the survey among the Happen Countries and the trend along the three period of time chosen of their state of energy efficiency, with the level of CO_2 emissions and of Primary Energy Consumptions caused by each stock.

In the present paragraph, cross-sectional analyses will be performed for those countries where data were available, so as to compare the behaviour of various countries towards energy efficiency during the three periods considered.

These comparisons among countries are presented in the following figures, first with reference to their PEC trends (figs. from 3.25 to 3.28) and then to their CO_2 emission trends (figs. from 3.29 to 3.32).

As can be seen from the graphs, the trends are almost always descending or stable over the years, with only few exceptions:

- With reference to PEC, we have to register a growing trend in the last period for the total m^2 of SFH of Greece and for the total m^2 of MFH of Spain and Slovenia (the reasons have been already esplained in the analysis of the single countries of the previous paragraphs);
- in the case of CO_2 emissions, we have a growing trend between the '80 and 2000 of Cyprus for the total m^2 of SFH and, at unit level, for MFH; Spain and Slovenia trends instead increase from 2000 onwards, but only with reference to the total m^2 of MFH.

As regards the values per m^2 of PEC, France has reached the lowest level in the last period for both SFH and MFH, in the second case together with Spain and Italy; the highest values are which of the Greece.

Also with reference to the values per m^2 of CO_2, France registers the lowest level in the last period for both SFH and MFH, together with Spain and Slovenia for MFH; the worst performance is that of Cyprus.

The comparison between countries on the values referred to the total m^2 is less significant because it depends a lot on their size and the consistency of their stock of buildings.

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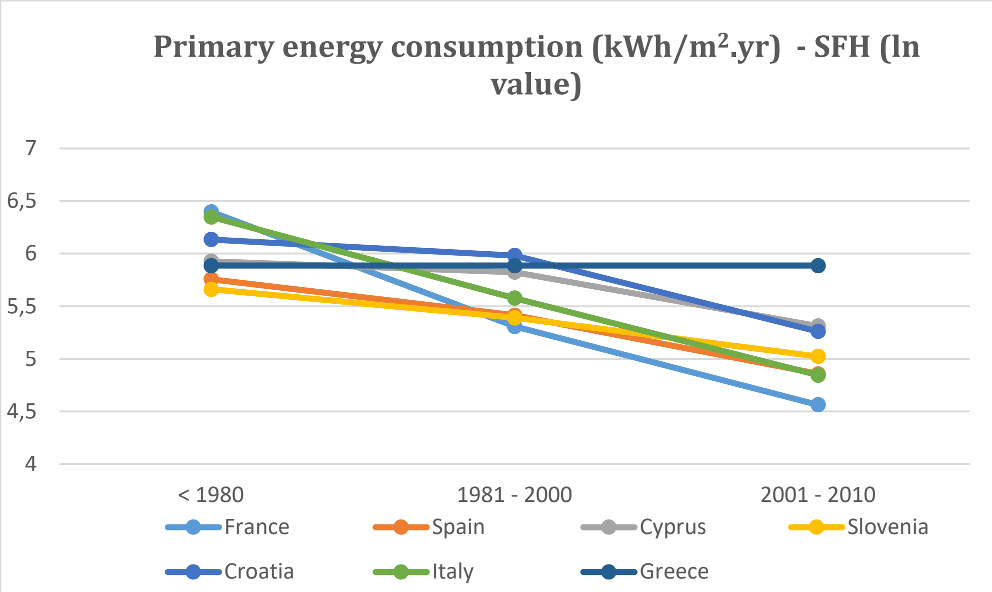

Figure 3.25 – PEC (kWh/m².yr), comparison among the countries trends for SFH

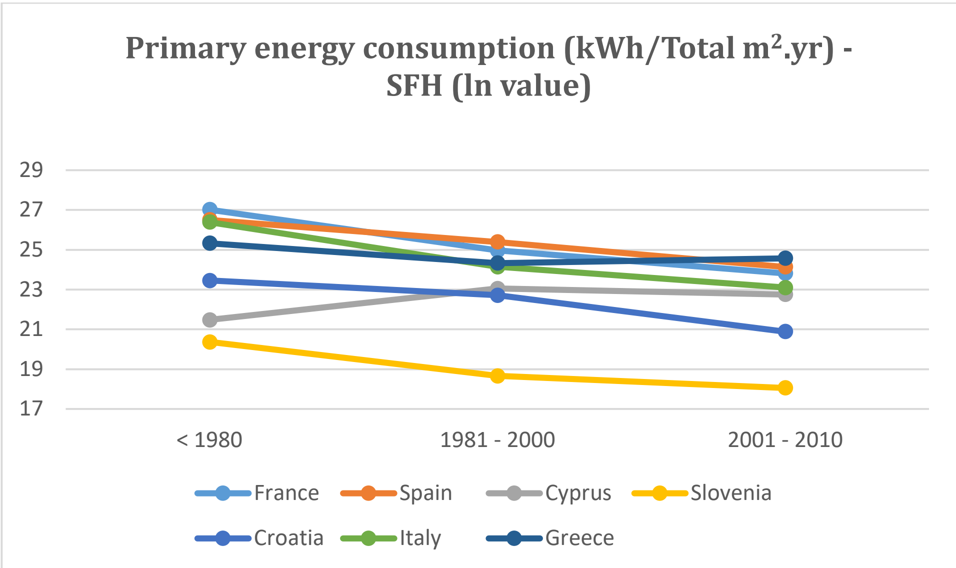

Figure 3.26 – PEC (kWh/Total m2.yr), comparison among the countries trends for SFH

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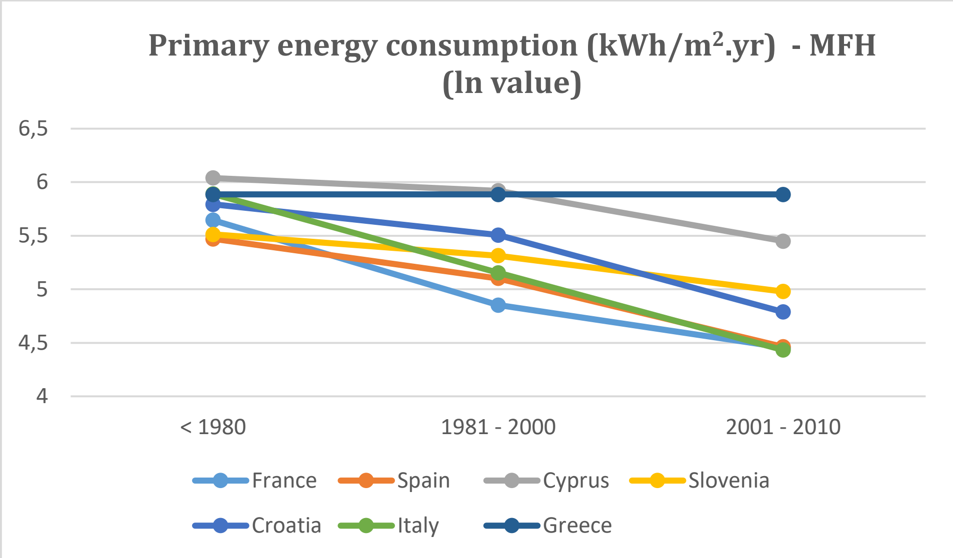

Figure 3.27 –– PEC (kWh/m^2.yr), comparison among the countries trends for MFH

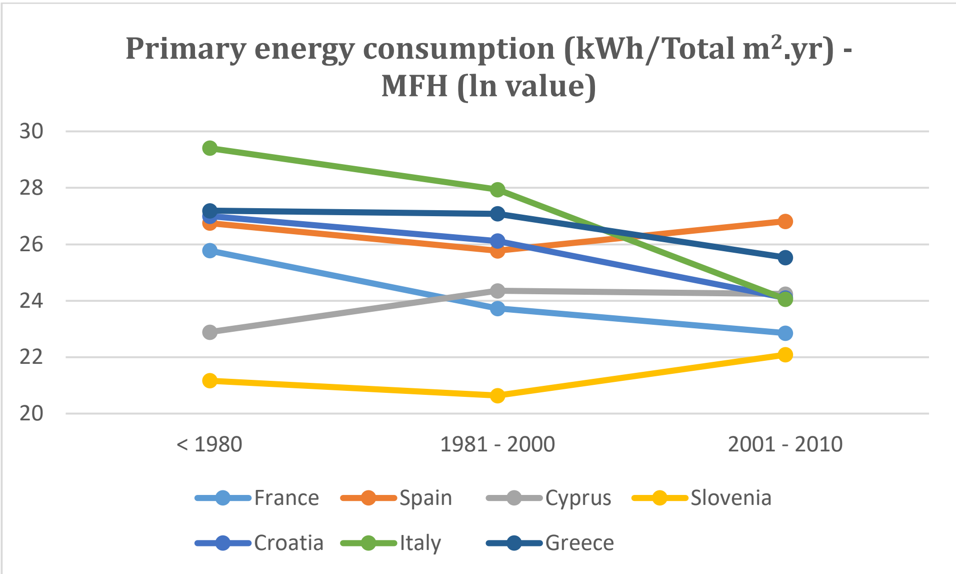

Figure 3.28 –– PEC (kWh/Total m^2.yr), comparison among the countries trends for MFH

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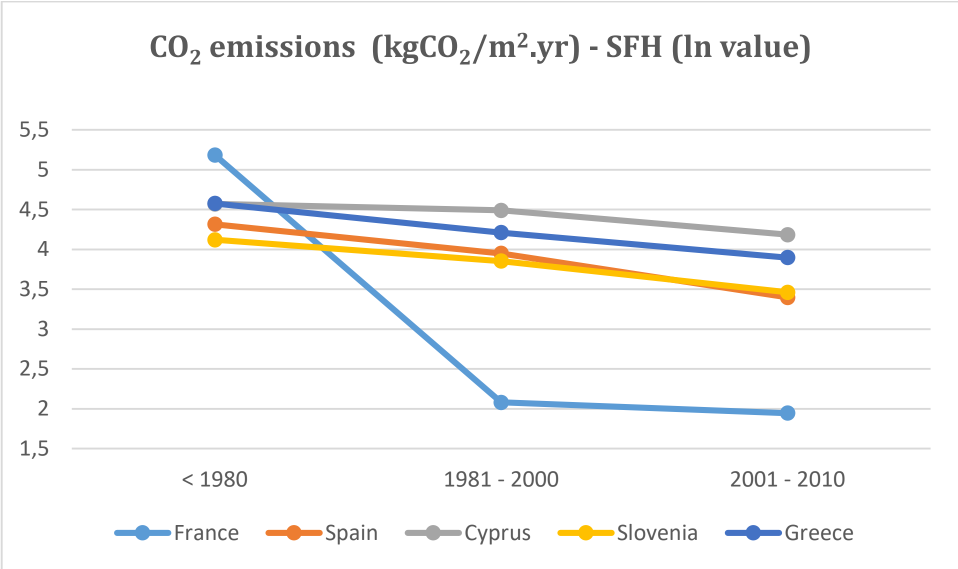

Figure 3.29 – CO_2 emissions ($kgCO_2/m^2$.yr), comparison among the countries trends for SFH

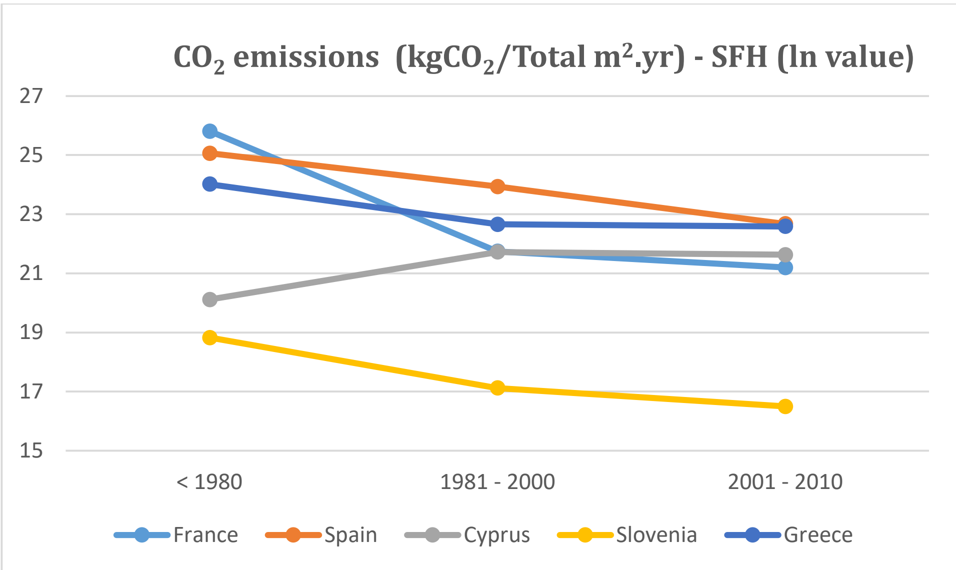

Figure 3.30 – CO_2 emissions ($kgCO_2$/Total m^2.yr), comparison among the countries trends for SFH

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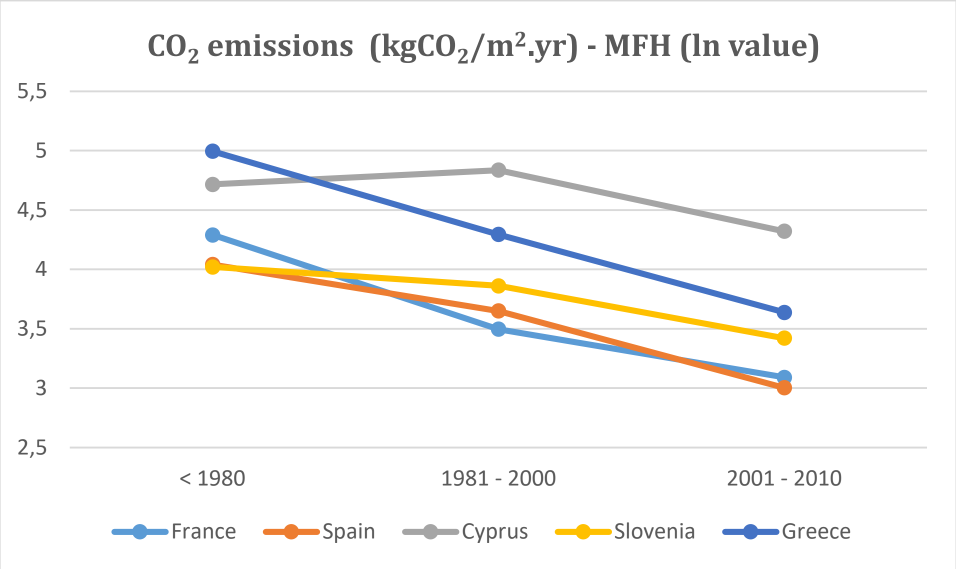

Figure 3.31– CO_2 emissions (kgCO_2/m^2.yr), comparison among the countries trends for MFH

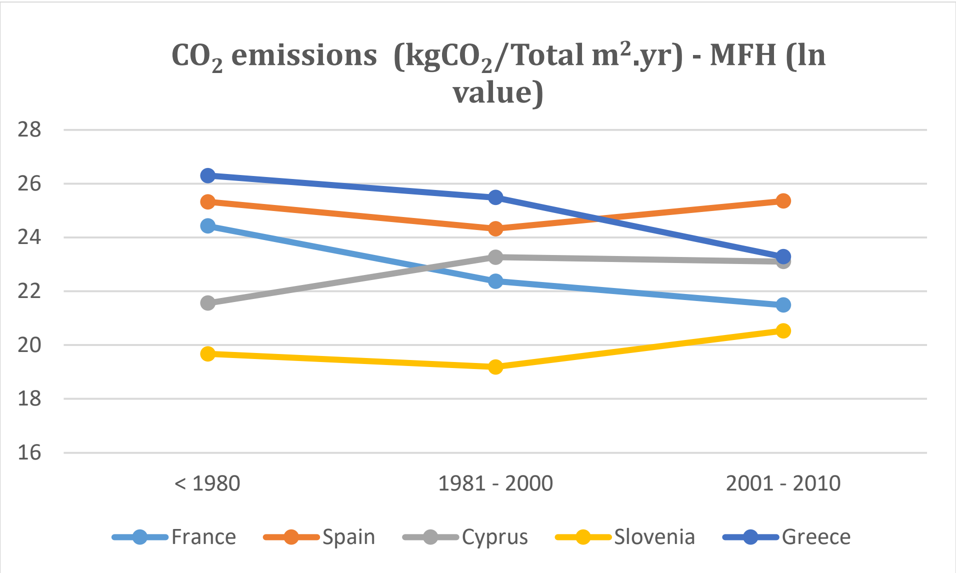

Figure 3.32 – CO_2 emissions (kgCO_2/Total m^2.yr), comparison among the countries trends for MFH

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4 ENVIRONMENTAL IMPACT AND ECONOMIC SAVINGS DUE TO RETROFITTING IN SOME REPRESENTATIVE COUNTRIES

The last part of this deliverable is dedicated to the countries for which a specific analysis was carried out in task 3.3 (D3.4), with the identification of their optimal POSs and corresponding Primary Energy Consumption (PEC) and CO_2 emissions: Spain, France, Cyprus and Croatia; as specified in report D3.4, they are also representative of the other countries of the Happen project.

For these 4 countries, using data and results of chapter 2 (i.e., DDF methodology) and chapter 3 (survey between the countries) of the present deliverable, a comparison will be made between before (current state of the stock of buildings emerging from the survey and related PEM and CO_2 emissions) and after retrofitting, in terms of possible environmental improvements and also economic savings, thanks to an economic evaluation of the CO_2 and the PEC saved.

The main idea is to estimate costs recovery referred to CO_2 and PEC if the pilot cases studies presented in deliverable D3.4 (i.e., Cyprus and Croatia for SFH; France and Spain for MFH) adopted the optimal solutions selected through the holistic efficiency scores in chapter 2. The model chosen for performing this economic analysis is the model#1, built considering as input the Life Cycle Cost (LCC) because this indicator combines both an evaluation of the costs and of the financial investment of the retrofitting intervention. We will use as benchmark the POS with the best holistic efficiency score and together the lowest PEC.

4.1 Scenarios of possible CO_2 savings by applying retrofitting to the buildings stock of each country

As regards CO_2 emissions, the analysis can only be carried out for 3 of the 4 pilots: with reference to the MFH for both France and Spain, but for the SFH only for Cyprus, as for the other nation (Croatia) which was analysed in D3.4, through the survey it was not possible to find the CO_2 data necessary for this comparison. The data are instead available for the PEC.

In the following tables we have collected for each country, with reference to CO_2, the values corresponding to the solution that resulted to be the most efficient in chapter 2 in terms of better LCC and lower CO_2 emissions (the best holistic efficiency score) and together the lowest PEC , for each POS identified in report D3.4.

In Tab.4.1 the best CO_2 values (with the corresponding PEC values) were averaged over the 4 climatic zones (identified for POS in D3.4), as the climatic zones resulting from the survey for the various regions were generally more or different in each country, so it would has been impossible find a direct match.

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CYPRUS – SFH	N°Solution with best CO_2 and lowest PEC in each POS	Primary Energy Consumptio - PEC (kWh/m2)	CO_2 Emissions (kg/m²)	CO_2 – average among climatic zones (kg/m²)	PEC – average among climatic zones (kg/m²)
W1S2	9	37,47	7,16	10,68	58,37
W2S2	6	47,51	8,71		
W2S3	9	72,72	13,73		
W3S2	10	75,79	13,14		
CROATIA - SFH					
W1S2	9	51,92	9,91	14,26	77,97
W2S2	9	86,22	16,28		
W2S3	3	69,15	12,63		
W3S2	1	104,6	18,23		
FRANCE - MFH					
W1S2	8	36,78	6,80	7,10	38,53
W2S2	9	31,78	5,86		
W2S3	7	41,03	7,95		
W3S2	6	44,52	7,77		
SPAIN – MFH					
W1S2	8	47,16	9,18	15,36	83,08
W2S2	11	75,37	13,52		
W2S3	9	94,68	18,83		
W3S2	6	115,12	19,93		

Table 4.1 - Best CO2 and PEC, corresponding to the solution that resulted to be the most efficient in each POS for each country

In the following tables (4.2, 4.3, 4.4), for each Country, has been inserted the following data:

- Total average m² (for each RB)
- Number of RBs
- CO_2 (Kg/m²), current emissions resulting from the survey of chapter 3
- best CO_2 for each POS corresponding to the solution that resulted to be the most efficient in chapter 2 with the DDF methodology (tab. 4.1): in terms of better LCC and lower CO_2 emissions (the best holistic efficiency score) and together the lowest PEC (with reference to the different climatic zones)
- Total Kg CO_2 that could be saved per year in each country thanks to deep retrofitting (difference between CO_2 from the survey and best CO_2 from the POS, multiplied for the total m²)
- Price CO_2 (Euro /kg)

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- Total hypothetical Euro saved per year thanks to retrofitting in each Country (Price CO_2 per Total Kg CO_2 saved per year)

We tried to evaluate in economic terms the CO_2 saved by using the official quotations (average 2019, equal to about 25 euro per ton of CO_2) of the so-called EUA (European Allowances).
The main measure adopted by the European Union to fulfill the commitments made by ratifying the Kyoto protocol is Directive 2003/87 / EC on the Emission Trading Scheme (ETS), which establishes a system for the exchange of Emission Allowances at EU level of CO_2, called EUA (EU Allowances). The EU ETS is the flagship policy for regulating carbon dioxide (CO_2) emissions in Europe. Being implemented in 2005, allowance prices in the EU ETS went through periods of highs and lows, from a level of around 10 euro/ton CO_2 for each EUA in March 2018, to 25 euro/ton CO_2 as average price for one EUA in 2019. The price of the units of EUA is defined by the market, based on the interaction between supply and demand. The volatility of the price of CO_2 emission rights is caused by a series of macroeconomic factors (offers to buy and sell, allocations at European level, etc.) to which other political, economic and environmental elements are added.

In the case of Cyprus, if all the SFHs present on the territory underwent a retrofitting intervention such as that envisaged by the solution of the POS that resulted to be the most efficient in chapter 2 in terms of better LCC and lower CO_2 emissions, the total CO_2 saved could be equal to 7.279.040.737 Kg per year, for an economic value of about 181.976.018 euro.

In the same way, in France and in Spain, with reference to all the MFH, the total CO_2 saved could be equal to respectively 42.117.095.618 and 29.711.051.206 Kg per year, with an economic value of about 1.052.927.390 and 742.776.280 euro.

Despite the high stock of MFH, it can be seen that Spain would achieve savings of CO_2 lower than those of France, because the buildings built in the last period, after 2001, already had excellent energy efficiency, often better than the target of CO_2 expected from the best solution of the POS.

Thanks to deep retrofitting, only adding the values of these 3 countries and for a part of the stock (SFH or MFH), the CO_2 saved could be of about 50 million of ton per year, equal to about 2 billion of euro as economic evaluation of the CO_2.

In table 4.5, starting from data of tables 4.2, 4.3, 4.5 on the total possible savings of CO_2(corresponding to the 100% of the building stock, as in the following scenario 1), we have hypothesized and compared three different Scenarios of possible CO_2 savings: by applying retrofitting to the whole building stock in each country (Scenario 1, 100%), to the 75% of the building stock (Scenario 2) and to the 50% of it (Scenario 3).We cannot know if and how long deep retrofitting will be applied to 100% of the building stock, as it depends on many factors, including above all the incentive system of each country and the availability and motivation of end users.

However if around a 67% of CO_2 saving is achieved applying retrofitting to the 100% of the buildings, overcaming the project target of 60%, the possible saving already reaches 50% with a 75% of coverage, therefore not too distant from that target.

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Cyprus	**SFH**							
Period	**Region**	**Total average m² per Building**	**N°of RBs**	**CO_2 emissions (Kg/m²) from survey)**	**Best CO_2 from POS**	**Total Kg CO_2 saved per year**	**Price CO_2 Euro/kg**	**Total Euro saved per year**
< 1980	**Larnaca**	112	10.083	106,8	7,16	112.503.640	0,025	2.812.591,01
	Limassol	112	12.604	135,3	7,16	180.958.801	0,025	4.523.970,04
	Nicosia	112	20.671	107,4	7,16	231.979.695	0,025	5.799.492,38
	Paphos	112	4.537	123,1	7,16	58.897.932	0,025	1.472.448,29
	Famagusta	112	2.521	106,1	7,16	27.932.552	0,025	698.313,81
						-	0,025	-
1981-	**Larnaca**	344	15.841	103,9	7,16	527.073.462	0,025	13.176.836,54
	Limassol	344	24.215	128,5	7,16	1.011.148.853	0,025	25.278.721,32
	Nicosia	344	29.615	103,0	7,16	976.696.038	0,025	24.417.400,94
	Paphos	344	11.302	109,1	7,16	396.383.849	0,025	9.909.596,24
	Famagusta	344	7.495	90,3	7,16	214.475.991	0,025	5.361.899,77
						-	0,025	-
2001-	**Larnaca**	576	11.356	103,9	7,16	346.381.030	0,025	8.659.525,75
	Limassol	576	12.819	128,5	7,16	557.534.801	0,025	13.938.370,03
	Nicosia	576	18.560	103,0	7,16	756.263.075	0,025	18.906.576,88
	Paphos	576	16.118	109,1	7,16	357.113.359	0,025	8.927.833,99
	Famagusta	576	6.480	90,3	7,16	204.061.430	0,025	5.101.535,75
						-	0,025	-
					TOTAL Kg CO_2 saved	**5.959.404.509 737**	**0,025**	**148.985.113 euro**

Table 4. 2- CYPRUS – SFH - possible CO_2 savings by applying retrofitting to the whole buildings stock

France	MFH						
Period	**Total average m²**	**N°of RBs (dwelling)**	**CO_2 emissions (Kg/m2)**	**Best CO_2 from POS**	**Total Kg CO_2 saved per year**	**Price CO_2 (UEA)**	**Total Euro saved per year**
< 1980	**66**	8.406.136	73,0	7,10	36.564.088.121	0,025	914.102.203
1981-	**71**	2.230.001	33,0	7,10	4.101.445.223	0,025	102.536.131
2001-	**54**	1.803.547	22,0	7,10	1.451.562.274	0,025	36.289.057
				TOTAL Kg CO_2 saved	**42.117.095.618**	0,025	**1.052.927.390 euro**

Table 4. 3 - FRANCE– MFH - possible CO_2 savings by applying retrofitting to the whole buildings stock

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Spain	**MFH**							
Period	**Regions**	**Total average m² per Building**	**N°of RBs**	**CO_2 emissions (Kg/m^2) (from survey)**	**Best CO_2 from POS**	**Total Kg CO_2 saved per year**	**Price CO_2 Euro/kg**	**Total Euro saved per year**
< 1980	ANDALUCIA	**1.440**	174.153	46,1	18,83	6.838.779.326	0,025	170.969.483
	ARAGON	**1.440**	36.663	68,4	13,93	2.873.088.662	0,025	71.827.217
	ASTURIAS	**1.440**	30.718	50,5	13,93	1.615.422.758	0,025	40.385.569
	BALEARES	**1.440**	37.353	53,7	9,18	2.392.067.920	0,025	59.801.698
	CANARIAS	**1.440**	59.151	43,2	9,18	2.893.638.099	0,025	72.340.952
	CATALUÑA	**1.440**	232.383	53,2	13,93	13.124.248.214	0,025	328.106.205
	CASTILLA LEON	**1.440**	66.960	90	13,93	7.330.030.848	0,025	183.250.771
	CASTILLA LA MANCHA	**1.440**	51.035	73	13,93	4.337.403.408	0,025	108.435.085
	EXTREMADURA	**1.440**	32.765	58,5	18,83	1.871.694.072	0,025	46.792.352
	GALICIA	**1.440**	81.766	50,5	13,93	4.299.975.821	0,025	107.499.396
	MURCIA	**1.440**	33.998	44,2	9,18	1.714.570.571	0,025	42.864.264
	NAVARRA	**1.440**	16.405	65,9	19,93	1.084.777.344	0,025	27.119.434
	PAIS VASCO	**1.440**	61.022	50,5	13,93	3.209.073.754	0,025	80.226.844
	RIOJA	**1.440**	10.822	68,4	13,93	848.063.866	0,025	21.201.597
	VALENCIA	**1.440**	163.291	44,2	9,18	8.235.012.150	0,025	205.875.304
	MADRID	**1.440**	108.795	73	13,93	9.246.356.496	0,025	231.158.912
	CANTABRIA	**1.440**	15.538	50,5	13,93	817.124.774	0,025	20.428.119
	CEUTA	**1.440**	1.288	53,7	9,18	82.482.892	0,025	2.062.072
	MELILLA	**1.440**	1.230	43,2	9,18	60.171.001	0,025	1.504.275
1981-2000	ANDALUCIA	**1.200**	116.579	31,9	18,83	1.828.425.036	0,025	45.710.626
	ARAGON	**1.200**	15.065	46,9	13,93	595.127.760	0,025	14.878.194
	ASTURIAS	**1.200**	45.222	33,5	13,93	1.059.280.128	0,025	26.482.003
	BALEARES	**1.200**	15.509	36,8	9,18	514.065.356	0,025	12.851.634
	CANARIAS	**1.200**	32.321	29,6	9,18	790.127.590	0,025	19.753.190
	CATALUÑA	**1.200**	77.928	36,3	13,93	2.087.223.552	0,025	52.180.589
	CASTILLA LEON	**1.200**	33.263	59,3	13,93	1.810.970.772	0,025	45.274.269
	CASTILLA LA MANCHA	**1.200**	30.261	49,4	13,93	1.286.213.544	0,025	32.155.339
	EXTREMADURA	**1.200**	20.108	40,7	18,83	527.714.352	0,025	13.192.859
	GALICIA	**1.200**	33.233	33,5	13,93	778.449.792	0,025	19.461.245
	MURCIA	**1.200**	21.277	30	9,18	531.632.667	0,025	13.290.817
	NAVARRA	**1.200**	6.556	44,3	19,93	191.723.664	0,025	4.793.092
	PAIS VASCO	**1.200**	14.388	33,5	13,93	337.024.512	0,025	8.425.613
	RIOJA	**1.200**	3.643	46,9	13,93	143.913.072	0,025	3.597.827
	VALENCIA	**1.200**	62.178	30	9,18	1.553.595.714	0,025	38.839.893
	MADRID	**1.200**	229.242	49,4	13,93	9.743.701.968	0,025	243.592.549
	CANTABRIA	**1.200**	34.430	33,5	13,93	806.488.320	0,025	20.162.208
	CEUTA	**1.200**	453	36,8	9,18	15.015.256	0,025	375.381
	MELILLA	**1.200**	769	29,6	9,18	18.799.174	0,025	469.979
2001-2010	ANDALUCIA	**7.064**	43.692	16,1	18,83	-842.587.986	0,025	-21.064.700
	ARAGON	**7.064**	7.369	25,4	13,52	615.806.107	0,025	15.395.153
	ASTURIAS	**7.064**	4.409	17,4	13,52	119.286.024	0,025	2.982.151
	BALEARES	**7.064**	69.798	18,9	9,18	4.768.752.049	0,025	119.218.801

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	CANARIAS	**7.064**	114.582	15,1	9,18	4.793.215.718	0,025	119.830.393
	CATALUÑA	**7.064**	32.512	19,4	13,52	1.350.428.836	0,025	33.760.721
	CASTILLA LEON	**7.064**	286.060	29,9	13,52	32.998.485.627	0,025	824.962.141
	CASTILLA LA MANCHA	**7.064**	13.437	26,8	13,52	1.255.777.947	0,025	31.394.449
	EXTREMADURA	**7.064**	5.819	21,7	18,83	117.972.544	0,025	2.949.314
	GALICIA	**7.064**	18.817	17,4	13,52	509.096.193	0,025	12.727.405
	MURCIA	**7.064**	12.159	15	9,18	500.048.451	0,025	12.501.211
	NAVARRA	**7.064**	4.329	24	19,93	124.460.828	0,025	3.111.521
	PAIS VASCO	**7.064**	9.705	17,4	13,52	262.569.940	0,025	6.564.248
	RIOJA	**7.064**	3.427	25,4	13,52	286.384.520	0,025	7.159.613
	VALENCIA	**7.064**	33.280	15	9,18	1.368.666.211	0,025	34.216.655
	MADRID	**7.064**	20.219	26,8	13,52	1.889.601.422	0,025	47.240.036
	CANTABRIA	**7.064**	41.782	17,4	13,52	1.130.417.024	0,025	28.260.426
	CEUTA	**7.064**	326	18,9	9,18	22.273.033	0,025	556.826
	MELILLA	**7.064**	571	15,1	9,18	23.886.179	0,025	597.154
					TOTAL Kg CO_2 saved	**52.137.128.653**	0,025	**1.303.428.216 euro**

Table 4. 4 - SPAIN – MFH - possible CO_2 savings by applying retrofitting to the whole buildings stoc

SCENARIO 1 (100% of the buildings stock)			
CO_2	**CO_2 Saved - 100%**	**Current emissions**	**% saving**
Croatia			
Cyprus	5.959.404.508,53	6.487.157.954,04	91,86%
Spain	52.137.128.653	250.042.030.948	20,85%
France	42.117.095.618	47.868.269.427	87,99%
Total			**66,90%**
SCENARIO 2 (75% of the buildings stock)			
CO_2	**CO_2 Saved - 75%**	**Current emissions**	**% saving**
Croatia			
Cyprus	4.469.553.381,40	6.487.157.954,04	68,90%
Spain	39.102.846.489,62	250.042.030.948	15,64%
France	31.587.821.713,50	47.868.269.427	65,99%
Total			**50,18%**
SCENARIO 3 (50% of the buildings stock)			

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CO_2	CO_2 Saved - 50%	Current emissions	% saving
Croatia			
Cyprus	2.979.702.254,27	6.487.157.954,04	45,93%
Spain	26.068.564.326,41	250.042.030.948	10,43%
France	21.058.547.809,00	47.868.269.427	43,99%
Total (average)			**33,45%**

Table 4.5 - Three Scenarios of possible CO_2 savings by applying retrofitting to 100%, 75% and 50% of the buildings stock in each country

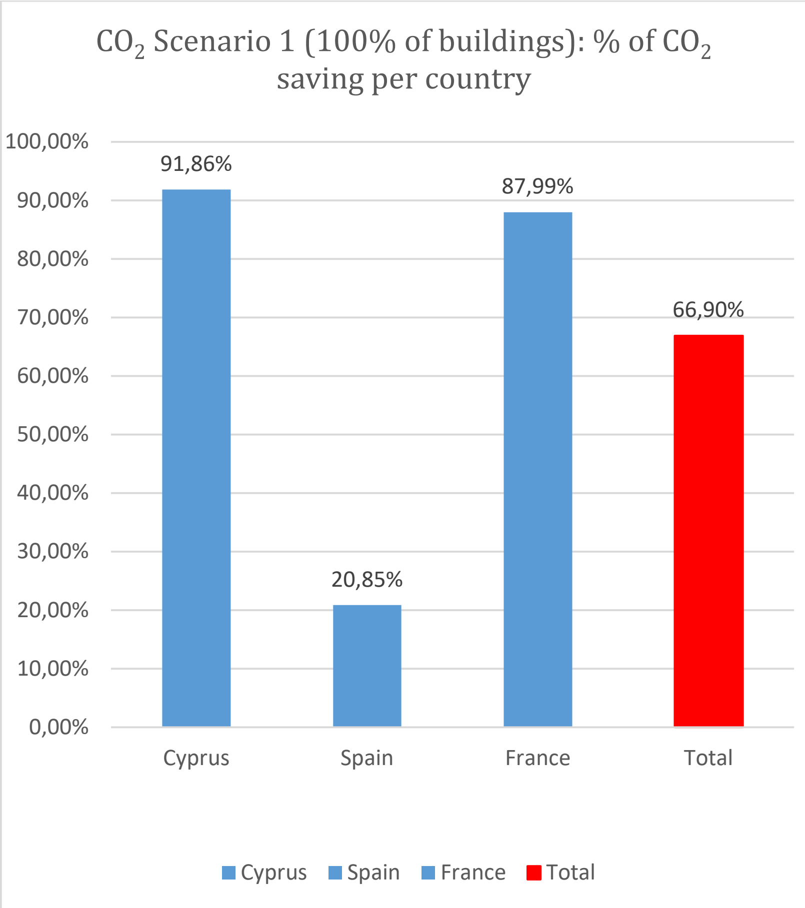

Figure 4.1 – Scenario 1 - possible CO_2 savings by applying retrofitting to the whole building stock

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4.2 Scenarios of possible Primary Energy Consumption (PEC) savings by applying retrofitting to the buildings stock of each country

In the following tables (4.6, 4.7, 4.8, 4.9) we have collected for each country, with reference to the PEC, the values corresponding to the solution that was most efficient in chapter 2 in terms of better LCC and lower PEC values for each POS identified in report D3.4.

The best PEC values were averaged over the 4 climatic zones identified for POS in D3.4 (tab.4.1), as the climatic zones resulting from the survey for the various regions were generally many more in each country, so it would has been impossible find a direct match.

In the following tables, for each Country, has been inserted the following data:

- Total average m^2 (for each RB)
- Number of RBs
- Current PEC (KWh/m^2) resulting from the survey of chapter 3
- best PEC for each POS, corresponding to the solution that resulted to be the most efficient in chapter 2 with the DDF methodology (tab. 4.1): in terms of better LCC and lower CO2 emissions (the best holistic efficiency score) and together the lowest PEC (with reference to the different climatic zones)
- Total kWh of PEC that could be saved per year in each country considered (difference between PEC from the survey and best PEC from the POS, multiplied for the total m^2).

Unlike CO_2, there is no official European quotation of kWh, but each country can, knowing the prices per kWh of its energy, calculate what its savings could be in economic terms.

In the case of Cyprus Croatia, if all the SFHs present on the territory underwent a retrofitting intervention such as that envisaged by the solution of the POS that resulted to be the most efficient in chapter 2 (in terms of better LCC and lower CO_2 emissions), the total PEC saved could be equal to, respectively, 16.109.144.346 and 21.296.557.625 kWh per year.

In the same way, in France and in Spain, with reference to all the MFH, the total PEC saved could be equal to respectively 154.424.947.499 and 346.949.755.414 KWh per year.

Thanks to deep retrofitting, only adding the values of these 4 countries and for a part of the stock (SFH or MFH), the PEC saved could be of about 539 billion of kWh per year.

These values give us only an initial idea of how many savings could be obtained if we extended the deep retrofitting to buildings in all European countries.

In table 4.10, starting from data of tables 4.6, 4.7, 4.8, 4.9 on the total possible savings of PEC (corresponding to the 100% of the building stock, as in the following scenario 1), we have hypothesized and compared three different Scenarios of possible PEC savings: by applying retrofitting to the whole building stock in each country (Scenario 1, 100%), to the 75% of the building stock (Scenario 2) and to the 50% of it (Scenario 3).

We cannot know if and how long deep retrofitting will be applied to 100% of buildings, as it depends on many factors, including above all the incentives system of each country and the availability and motivation of end users. However if with a 100% coverage of the buildings stock we could achieve around 74% of PEC savings, overcoming the project target of 60%, even with a 75% of coverage the possible savings already would reach the 55.5%, almost close to our target.

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Cyprus SFH						
Period	**Region**	**Total average m² per Building**	**N°of RBs**	**PEC (kWh/m²) (from survey)**	**Best PEC from POS (kWh/m²)**	**Total kWh PEC saved per year**
< 1980	**Larnaca**	**112**	10.083	305,2	37,467	302.313.698
	Limassol	**112**	12.604	411,3	37,47	527.772.568
	Nicosia	**112**	20.671	391,1	37,47	818.626.471
	Paphos	**112**	4.537	450,5	37,47	209.926.905
	Famagusta	**112**	2.521	317,7	37,47	79.110.773
						-
1981-2000	**Larnaca**	**344**	15.841	289,5	37,47	1.373.517.938
	Limassol	**344**	24.215	384,9	37,47	2.894.081.590
	Nicosia	**344**	29.615	366,5	37,47	3.352.384.680
	Paphos	**344**	11.302	321,9	37,47	1.105.688.541
	Famagusta	**344**	7.495	328,2	37,47	749.714.779
						-
2001-2010	**Larnaca**	**576**	11.356	185,9	37,47	971.051.383
	Limassol	**576**	12.819	255,7	37,47	1.611.194.647
	Nicosia	**576**	18.560	240,9	37,47	2.175.147.197
	Paphos	**576**	16.118	141,1	37,47	962.220.099
	Famagusta	**576**	6.480	191,2	37,47	573.928.978
						-
					TOTAL kWh PEC saved	**17.706.680.248**

Table 4.6 - CYPRUS – SFH - possible PEC savings by applying retrofitting to the whole buildings stock

Croatia SFH						
Period	**Region**	**Total average m² per building**	**N°of RBs**	**PEC (kWh/m²) (from survey)**	**Best PEC from POS (kwh/m²)**	**Total kWh PEC saved per year**
< 1980	Zagrebačka	**72**	40.666	544	104,60	1.286.542.109
	Krapinsko-zagorska	**72**	23.990	544	104,60	758.966.832
	Sisačko-moslavačka	**72**	26.915	544	104,60	851.504.472
	Karlovačka	**72**	18.107	544	104,60	572.847.538
	Varaždinska	**72**	25.845	544	104,60	817.653.096
	Koprivničko-križevačka	**72**	19.713	544	104,60	623.656.238
	Bjelovarsko-bilogorska	**72**	21.629	544	104,60	684.272.347
	Primorsko-goranska	**72**	19.289	256	86,22	235.791.822
	Ličko-senjska	**72**	8.069	544	104,60	255.277.339
	Virovitičko-podravska	**72**	15.466	544	104,60	489.294.749
	Požeško-slavonska	**72**	11.505	544	104,60	363.981.384
	Brodsko-posavska	**72**	22.794	544	104,60	721.129.219
	Zadarska	**72**	15.044	256	86,22	183.900.263
	Osječko-baranjska	**72**	43.485	544	104,60	1.375.726.248
	Šibensko-kninska	**72**	11.791	256	86,22	144.135.071

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	Vukovarsko-srijemska	**72**	24.873	544	104,60	786.902.126
	Splitsko-dalmatinska	**72**	26.365	256	86,22	322.289.978
	Istarska	**72**	15.920	256	86,22	194.608.627
	Dubrovačko-neretvanska	**72**	10.775	256	86,22	131.715.324
	Međimurska	**72**	17.106	544	104,60	541.179.101
	Grad Zagreb	**72**	37.367	544	104,60	1.182.172.306
	Undefined	**72**	3.838			-
1981-2000	Zagrebačka	**95**	18.772	467	104,60	646.282.416
	Krapinsko-zagorska	**95**	7.588	467	104,60	261.239.664
	Sisačko-moslavačka	**95**	12.145	467	104,60	418.128.060
	Karlovačka	**95**	7.729	467	104,60	266.094.012
	Varaždinska	**95**	10.103	467	104,60	347.826.084
	Koprivničko-križevačka	**95**	7.764	467	104,60	267.298.992
	Bjelovarsko-bilogorska	**95**	7.920	467	104,60	272.669.760
	Primorsko-goranska	**95**	5.557	220	86,22	70.624.469
	Ličko-senjska	**95**	2.995	467	104,60	103.111.860
	Virovitičko-podravska	**95**	6.346	467	104,60	218.480.088
	Požeško-slavonska	**95**	5.613	467	104,60	193.244.364
	Brodsko-posavska	**95**	10.687	467	104,60	367.932.036
	Zadarska	**95**	6.868	220	86,22	87.286.099
	Osječko-baranjska	**95**	20.420	467	104,60	703.019.760
	Šibensko-kninska	**95**	4.023	220	86,22	51.128.709
	Vukovarsko-srijemska	**95**	15.553	467	104,60	535.458.684
	Splitsko-dalmatinska	**95**	9.400	220	86,22	119.465.540
	Istarska	**95**	6.360	220	86,22	80.829.876
	Dubrovačko-neretvanska	**95**	3.443	220	86,22	43.757.431
	Međimurska	**95**	8.021	467	104,60	276.146.988
	Grad Zagreb	**95**	14.756	467	104,60	508.019.568
	Undefined	**95**	2.276			-
2001-2010	Zagrebačka	**95**	6.171	227	104,60	71.756.388
	Krapinsko-zagorska	**95**	1.514	227	104,60	17.604.792
	Sisačko-moslavačka	**95**	3.147	227	104,60	36.593.316
	Karlovačka	**95**	1.687	227	104,60	19.616.436
	Varaždinska	**95**	2.624	227	104,60	30.511.872
	Koprivničko-križevačka	**95**	1.742	227	104,60	20.255.976
	Bjelovarsko-bilogorska	**95**	1.964	227	104,60	22.837.392
	Primorsko-goranska	**95**	2.567	107	86,22	5.067.515
	Ličko-senjska	**95**	1.472	227	104,60	17.116.416
	Virovitičko-podravska	**95**	1.723	227	104,60	20.035.044
	Požeško-slavonska	**95**	2.044	227	104,60	23.767.632
	Brodsko-posavska	**95**	3.647	227	104,60	42.407.316

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	Zadarska	**95**	3.105	107	86,22	6.129.581
	Osječko-baranjska	**95**	5.551	227	104,60	64.547.028
	Šibensko-kninska	**95**	1.535	107	86,22	3.030.244
	Vukovarsko-srijemska	**95**	4.926	227	104,60	57.279.528
	Splitsko-dalmatinska	**95**	3.366	107	86,22	6.644.821
	Istarska	**95**	2.928	107	86,22	5.780.165
	Dubrovačko-neretvanska	**95**	977	107	86,22	1.928.696
	Međimurska	**95**	2.646	227	104,60	30.767.688
	Grad Zagreb	**95**	5.439	227	104,60	63.244.692
	Undefined	**95**	3.326			-
					TOTAL kWh PEC saved	**18.928.513.185**

Table 4.7: CROATIA – SFH - possible PEC savings by applying retrofitting to the whole buildings stock

France	**MFH**					
Period	**Region**	**Total average m² per dwelling**	**N°of RBs**	**PEC (kWh/m²) (from survey)**	**Best PEC from POS (kwh/m2)**	**Total kWh PEC saved per year**
< 1980		**66**	8.406.136	283	38,53	135.635.094.047
						-
1981-2000		**71**	2.230.001	128	38,53	14.166.339.828
						-
2001-2010		**54**	1.803.547	86	38,53	4.623.513.624
						-
					TOTAL kWh PEC saved	**154.424.947.499**

Table 4.8 - FRANCE – MFH - possible PEC savings by applying retrofitting to the whole buildings stock

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Spain	**MFH**					
Period	**Region**	**Total average m² per Building**	**N°of RBs**	**PEC (kWh/m²) (from survey)**	**Best PEC from POS (kwh/m²)**	**Total kWh PEC saved per year**
< 1980	ANDALUCIA	1.440	174.153	192,6	94,68	24.556.408.934
	ARAGON	1.440	36.663	308,9	75,37	12.329.150.962
	ASTURIAS	1.440	30.718	213	75,37	6.087.914.410
	BALEARES	1.440	37.353	191,45	47,15886799	7.761.177.582
	CANARIAS	1.440	59.151	153,4	47,15886799	9.049.347.648
	CATALUÑA	1.440	232.383	226,7	75,37	50.639.787.922
	CASTILLA LEON	1.440	66.960	389,3	75,37	30.269.884.032
	CASTILLA LA MANCHA	1.440	51.035	317,45	75,37	17.790.556.032
	EXTREMADURA	1.440	32.765	252,4	94,68	7.441.481.952
	GALICIA	1.440	81.766	213	75,37	16.204.974.595
	MURCIA	1.440	33.998	181,55	47,15886799	6.579.402.777
	NAVARRA	1.440	16.405	295	105	4.488.408.000
	PAIS VASCO	1.440	61.022	213	75,37	12.093.779.318
	RIOJA	1.440	10.822	308,9	75,37	3.639.256.790
	VALENCIA	1.440	163.291	181,55	47,15886799	31.600.601.766
	MADRID	1.440	108.795	317,45	75,37	37.925.414.784
	CANTABRIA	1.440	15.538	213	75,37	3.079.432.714
	CEUTA	1.440	1.288	191,45	47,15886799	267.619.648
	MELILLA	1.440	1.230	153,4	47,15886799	188.174.293
1981-2000	ANDALUCIA	1.200	116.579	134,55	94,68	5.577.605.676
	ARAGON	1.200	15.065	210,5	75,37	2.442.880.140
	ASTURIAS	1.200	45.222	146,7	75,37	3.870.822.312
	BALEARES	1.200	15.509	135,7	47,15886799	1.647.821.300
	CANARIAS	1.200	32.321	108,25	47,15886799	2.369.431.773
	CATALUÑA	1.200	77.928	158,2	75,37	7.745.731.488
	CASTILLA LEON	1.200	33.263	259,45	75,37	7.347.663.648
	CASTILLA LA MANCHA	1.200	30.261	220,7	75,37	5.277.397.356
	EXTREMADURA	1.200	20.108	176,4	94,68	1.971.870.912
	GALICIA	1.200	33.233	146,7	75,37	2.844.611.868
	MURCIA	1.200	21.277	126,9	47,15886799	2.035.982.479
	NAVARRA	1.200	6.556	200,05	105	747.777.360
	PAIS VASCO	1.200	14.388	146,7	75,37	1.231.555.248
	RIOJA	1.200	3.643	210,5	75,37	590.734.308
	VALENCIA	1.200	62.178	126,9	47,15886799	5.949.772.928
	MADRID	1.200	229.242	220,7	75,37	39.978.887.832
	CANTABRIA	1.200	34.430	146,7	75,37	2.947.070.280
	CEUTA	1.200	453	135,7	47,15886799	48.130.959
	MELILLA	1.200	769	108,25	47,15886799	56.374.897
2001-2010	ANDALUCIA	7.064	43.692	69,4	94,68	-7.802.426.481
	ARAGON	7.064	7.369	112,5	75,37	1.932.787.892

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	ASTURIAS	7.064	4.409	77,05	75,37	52.323.896
	BALEARES	7.064	69.798	71,6	47,15886799	12.050.775.223
	CANARIAS	7.064	114.582	56,6	47,15886799	7.641.720.682
	CATALUÑA	7.064	32.512	85,4	75,37	2.303.537.623
	CASTILLA LEON	7.064	286.060	133,8	75,37	118.071.127.691
	CASTILLA LA	7.064	13.437	118,25	75,37	4.070.125.348
	EXTREMADURA	7.064	5.819	94,75	94,68	2.877.379
	GALICIA	7.064	18.817	77,05	75,37	223.311.124
	MURCIA	7.064	12.159	65,05	47,15886799	1.536.690.369
	NAVARRA	7.064	4.329	107,15	105	65.747.120
	PAIS VASCO	7.064	9.705	77,05	75,37	115.174.282
	RIOJA	7.064	3.427	112,5	75,37	898.855.219
	VALENCIA	7.064	33.280	65,05	47,15886799	4.206.024.794
	MADRID	7.064	20.219	118,25	75,37	6.124.422.446
	CANTABRIA	7.064	41.782	77,05	75,37	495.848.721
	CEUTA	7.064	326	71,6	47,15886799	56.284.603
	MELILLA	7.064	571	56,6	47,15886799	38.081.221
					TOTAL kWh PEC saved	**528.758.186.075**

Tab. 4.9: SPAIN – MFH - possible PEC savings by applying retrofitting to the whole building stock

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SCENARIO 1 (100% of the buildings stock)			
PEC	**PEC Saved, 100%**	**Current emissions**	**% saving**
Croatia	18.928.513.185	24.661.782.483	76,75%
Cyprus	17.706.680.248	20.468.381.494	86,51%
Spain	528.758.186.075	1.071.903.427.664	49,33%
France	154.424.947.499	185.651.729.564	83,18%
Total			**73,94%**
SCENARIO 2 (75% of the buildings stock)			
PEC	**PEC Saved, 75%**	**Current emissions**	**% saving**
Croatia	14.196.384.889	24.661.782.483	57,56%
Cyprus	13.280.010.186	20.468.381.494	64,88%
Spain	396.568.639.556	1.071.903.427.664	37,00%
France	115.818.710.624	185.651.729.564	62,38%
Total			**55,46%**
SCENARIO 3 (50% of the buildings stock)			
PEC	**PEC Saved, 50%**	**Current emissions**	**% saving**
Croatia	9.464.256.593	24.661.782.483	38,38%
Cyprus	8.853.340.124	20.468.381.494	43,25%
Spain	264.379.093.038	1.071.903.427.664	24,66%
France	77.212.473.750	185.651.729.564	41,59%
Total			**36,97%**

Table 4.10 - Three Scenarios of possible PEC savings by applying retrofitting to the 100%, 75% and 50% of the buildings stock in each country

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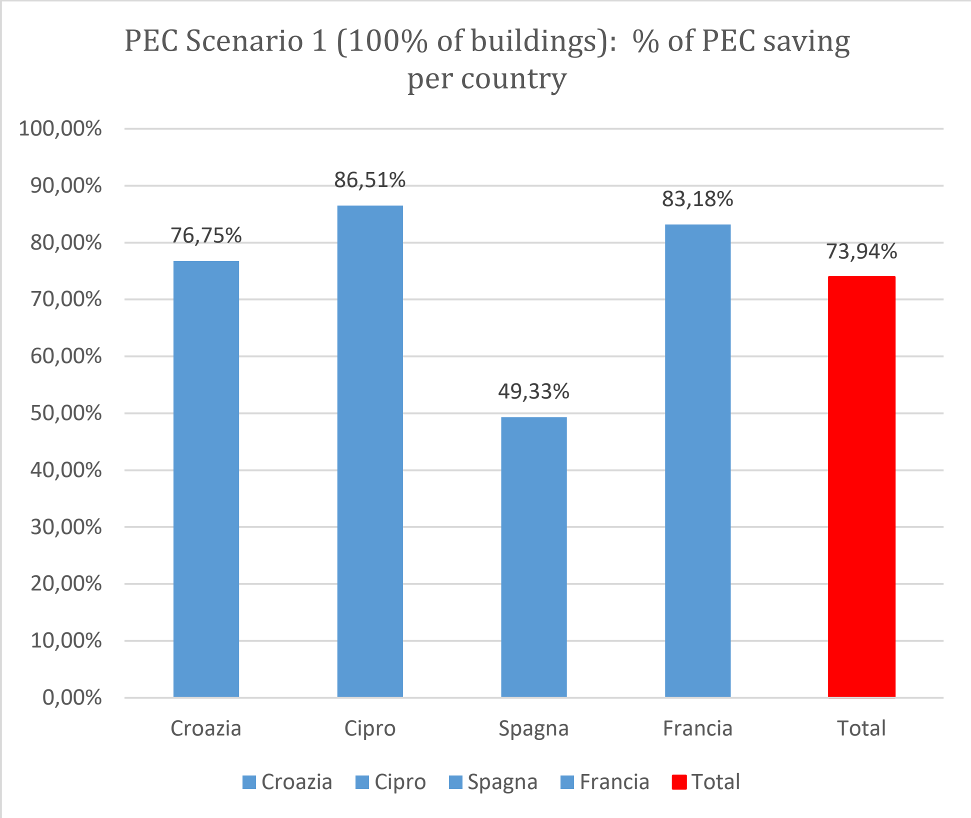

Figure 4.2 – Scenario 1 - possible PEC savings by applying retrofitting to the whole buildings stock

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5 CONCLUSIONS AND RECOMMENDATIONS

The International Panel of Climate Change stated that there would be a steady increase in the ambient temperature during the end of the 21st century. This increase will affect the built environment, particularly the requirements of energy used for buildings. Many studies discuss issues related to the potential impact of global warming on energy use and these issues could be particularly topical for the warm climate of the Mediterranean Countries.

Measures on the energy efficiency of buildings are very important because more and more studies are showing that, unlike what was previously thought, i.e. thermal systems for heating buildings have an impact on total CO_2 emissions in urban areas, which is up to 6 times higher than the incidence of vehicular traffic.

To improve the air quality in our cities today it is then necessary to focus attention not only on the concept of sustainable mobility, but also on that of sustainable building and heating, adopting energy requalification interventions such as those proposed by the Happen project.

Also for these reasons, in this deliverable of the Happen project, we have tried to evaluate what is the global impact of CO_2 and of Energy consumption deriving from buildings in the Project countries, and what savings could be obtained thanks to the proposed retrofitting activities, if applied to all the stock of existing buildings; furthermore we have tried to set a method to calculate " the holistic impact of the renovation interventions" or at least to hypothesize it.

In a complementary manner to T3.3, we have tried to set an economic evaluation of the retrofit investment, not only from a financial point of view, but also from an environmental and social one, first through the comparison of the different solutions of retrofitting also from this point of view in order to define, for each Package of Optimal Solutions (POS) identified in the previous deliverables, the environmental and economic sustainable better solution, using combining results from Life Cycle Costing (i.e., LCC) and non-parametric technique (i.e. DDF methodology).

Moreover, the positive externalities due to reduction of energy consumption and less CO_2 emissions have been evaluate, also economically, thanks to the data of a survey carried out among the project partners. For each country, a single analysis have been carried out (with the construction of country files) while, for those whose where data have resulted to be available, a cross-sectional analyses has been performed, to compare how the various countries behaved in terms of energy efficiency during the three periods considered.

From this analysis it emerged that over the years (considering three periods of construction of the buildings) the situation in terms of energy saving and CO_2 emissions has greatly improved in more recent buildings; unfortunately, in almost all the countries considered, the majority of the buildings were built before 2001 or even worse before 1980, so retrofitting results to be very necessary to reduce the environmental and economic impact of these buildings. However the PEC and CO_2 emissions trends over the time emerged from the cross-sectional analyses among the various countries are resultated to be almost always descending or stable over the years, with only few exceptions.

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For giving an idea of the environmental and economic impact of the existing buildings, for some countries, using data and results of the DDF methodology and of the survey between the countries, a comparison was made between before (current state of the stock of building emerging from the survey and related Primary Energy Consumption and CO_2 emissions) and after deep retrofitting, in terms of possible environmental improvements and also economic savings.

The main idea has been to estimate costs recovery referred to CO_2 and Primary Energy Consumption (PEC) if the buildings of the pilot cases studies presented in deliverable D3.4 adopted the optimal solution selected through the holistic efficiency scores developed in the present deliverable.

From this kind of analysis, we found out that, thanks to deep retrofitting, only adding the values of 3 countries and for a part of the stock (SFH for Cyprus and MFH for France and Spain), the CO_2 saved could be already of about 50 million of ton per year, equal to about 2 billion of euro as economic evaluation of the CO_2.

This result could be obtained in the scenario 1, corresponding to the situation in which retrofitting would be applied to all that stocks of buildings. In this case we could achieve around 67% of CO_2 savings, overcoming the project target of 60%, but even with a 75% of coverage of buildings (scenario 2) the possible savings already would reach the 50%, not too distant from our target.

In the same way, always thanks to deep retrofitting, only adding the values of 4 countries and for a part of the stock (SFH for Cyprus and Croatia and MFH for France and Spain), the PEC saved could be of about 539 billion of kWh per year (always with reference to the scenario 1). With a 100% coverage of the buildings stock we could achieve around 74% of PEC savings, overcoming the project target of 60%, but even with a 75% of coverage the possible savings already would reach the 55.5%, almost close to our target.

These values give us only an initial idea of how many savings we could be obtained if we extended the deep retrofitting to all kind of buildings in all European countries.

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