UNIVERSITÀ DEGLI STUDI DI PADOVA

UNIVERSITÀ DEGLI STUDI DI PADOVA

Sede Amministrativa: Università degli Studi di Padova

Dipartimento di Ingegneria Industriale

SCUOLA DI DOTTORATO DI RICERCA IN INGEGNERIA INDUSTRIALE

INDIRIZZO INGEGNERIA DELL'ENERGIA

CICLO XXVI

INNOVATIVE INTEGRATED SOLUTIONS FOR THE REDUCTION OF THE ENERGY DEMAND AND FOR THE DEVELOPMENT OF THE RENEWABLE RESOURCES IN RESIDENTIAL BUILDINGS

Direttore della Scuola: Ch.mo Prof. Paolo Colombo

Coordinatore d'indirizzo: Ch.mo Prof. Luisa Rossetto

Supervisore: Ch.mo Prof. Michele De Carli

Dottoranda: Samantha Graci

SUMMARY

One of the primary European Union's "Europe 2020" energy strategies is the reduction of the total energy consumption by means of energy efficiency improvements. In the European Union (EU) the building sector is responsible of about the 40% of the total final energy consumption and of the 36% of the Europe global CO_2 *emissions. During the last decade the European Commission released the first legislative instrument aimed to improve the energy performance of buildings: the "Energy Performance of Building Directive (EPBD) was introduced in 2002 and updated in 2010. The first edition of the document focused the analysis on new buildings, in order to promote the diffusion of energy efficient buildings, characterized by very low energy demand, possibly almost zero energy buildings. The recast of the document introduces the important topic of the existing building stock. It presents and discusses the recommendations that the European Commission released so far and focused on the possibilities of increasing the energy efficiency of buildings according to feasible retrofit strategies. The renovation of the existing building stock and the improvement of the energy performance are expected to have a key role in the increasing of European energy efficiency as well, considering that the 75% of the future stock has already been built.*

This thesis aims to investigate the possibilities of energy saving existing in the residential building sector. Some case studies will be presented with integrated HVAC systems based on different sources (multi-energy systems) combined to operate in the most suitable conditions to achieve higher efficiency performance as a whole. This type of system will be referred as IMES (Integrated Multi-Energy Systems). IMES performance will be evaluated according to new and retrofitted buildings, in order to investigate different plant configurations performances and to determine the extension of their applicability domain.

The first chapter provides an overview of the European building stock, in order to comprehend the magnitude of the issue. The composition and the age of the existent buildings are analyzed as well as the actual energy consumption according to the final uses. Based on the described situation, the requirements introduced by the EPBD are analyzed according to new and existent buildings.

The second chapter presents an analysis carried out to assess the effectiveness, in terms of reduction of primary energy demand, of the retrofit of the building envelope and of the HVAC system in a single dwelling house. The analysis has been realized by the means of dynamic simulations carried out by means of the commercial transient code TRNSYS. A model of the building and of the thermal system has been implemented according to the situation before the retrofit, and several redevelopment actions have been evaluated in order to achieve the maximum energy saving.

The third chapter presents an activity which aimed to esteem the performance analysis of an IMES conceived to serve a multi-residential building. The main purposes are: to identify the configuration of the system that maximize the contribution of the renewable energy resources, i.e. solar energy and the renewable share due to the use of an heat pump; to set the mathematical model of the thermal storage by the means of experimental measurements, in order to better replicate the behaviors of real storages; to investigate the possibility of extending the applicability domain of the IMES to traditional buildings, equipped with non-insulated envelopes and radiators as emissions devices.

The fourth chapter presents an analysis on the energy saving possibilities according to the retrofit of the European building stock. The work has considered the composition of the dwellings around Europe, identifying a general classification of the existent buildings. The analysis has been conducted *on the basis of four case studies which have been subjected to an energy performance analysis, according to the status before and after a major renovation of the building envelope and of the HVAC system. The energy performance has been evaluated by means of dynamic simulations carried out with the commercial software TRNSYS. The work aims to evaluate the possible energy savings due to the renovation of the buildings into low energy buildings; to achieve this goal 20 simulation have been carried out on the buildings models, and 80 simulations have been necessary to conclude the analysis on the performance of the HVAC system. Four cities have been considered in the study to assess the effects of the redevelopment in different European climate conditions: Budapest, Venice, Athens and Helsinki.*

SOMMARIO

Uno dei principali obiettivi del programma energetico europeo "Europe 2020" é la riduzione dei consumi finali di energia per mezzo di interventi mirati ad incrementale l'efficienza energetica.
Nell'Unione Europea (EU) il settore edilizio é responsabile di circa il 40% dei consumi finali di energia e del 36% delle emissioni di CO_2. Nel corso dell'ultimo decennio la Commissione Europea ha emanato il primo strumento legislativo mirato ad incrementale l'efficienza energetica del settore edilizio: la "Direttiva sull'Efficienza Energetica negli Edifici" (EPDB) é stata introdotta nel 2002 e successivamente aggiornata nel 2010. La prima edizione del documento focalizzava l'attenzione sugli edifici di nuova costruzione, con l'obiettivo di promuovere la diffusione di edifici energeticamente efficienti; la revisione introduce l'importante tema del parco edilizio esistente, mettendo in luce le possibilità connesse all'incremento dell'efficienza energetica degli edifici esistenti, per mezzo di strategie di retrofit mirate. Il rinnovamento del parco edilizio esistente e l'incremento delle prestazioni energetiche ricopriranno un ruolo determinante a livello europeo verso l'incremento complessivo dell'efficienza energetica.
La presente tesi si propone di investigare quali possibilità di risparmio energetico risiedono nel settore residenziale. Sono presentati alcuni casi studio in cui i sistemi di climatizzazione HVAC sono stati analizzati per verificarne le capacità di soddisfare i fabbisogni energetici attraverso l'impiego di differenti sistemi di generazione (sistemi multi energia) combinati per operare ciascuno nelle condizioni di lavoro più favorevoli (sistemi integrati). La tipologia di impianti descritta viene definita IMES dall'acronimo inglese di sistemi integrati multi - energia. . Le prestazioni dei sistemi IMES sono state analizzate in relazione all'installazione presso edifici di nuova costruzione ed edifici ristrutturati, in modo da valutare le prestazioni di diverse configurazioni impiantistiche e di determinare il campo di applicabilità di tali sistemi
Il primo capitolo fornisce una panoramica dello stato e della composizione del parco edilizio Europeo, al fine di comprendere l'entità del tema trattato. Sono presentati, inoltre, i dati riguardanti i consumi energetici relativi al settore edilizio che sono stati analizzati e discussi in relazione alle disposizioni introdotte dalla CE tramite l'EPBD e al suo aggiornamento.
Il secondo capitolo presenta un'analisi condotta per verificare l'efficacia in termini di risparmio di energia primaria di un sistema IMES abbinato a un'abitazione monofamiliare. L'analisi si é servita di simulazioni dinamiche operate con il software commerciale TRNSYS, per mezzo delle quali sono stati creati un modello dell'involucro edilizio e un modello dell'impianto che sono stati quindi integrati per valutare le prestazioni energetiche complessive. Sono state valutate le condizioni pre e post rinnovamento dell'edificio e sono state, inoltre, considerate diverse configurazioni impiantistiche in modo da determinare quella capace di generare il massimo risparmio in termini di energia primaria.
Il terzo capitolo riguarda l'analisi delle prestazioni dei sistemi IMES applicati ad un complesso residenziale di trenta unità abitative. Lo scopo principale é quello di valutare le prestazioni del sistema e di massimizzare il contributo di energia delle fonti rinnovabili, ovvero del sistema solare termico integrato e della quota di energia rinnovabile associabile al funzionamento dei sistemi dotati di pompa di calore. Si e' voluto inoltre migliorare la compatibilità' tra i sistema reale e la simulazione dinamica mediante una serie di test di laboratorio e di successive calibrazioni del modello matematico degli accumuli termici. Infine l'analisi e' stata estesa ad applicazioni del sistema IMES in edifici non

ristrutturati, caratterizzati da involucri dalle basse performance energetiche e equipaggiati con sistemi di emissione del calore ad alta temperatura, quali i tradizionali radiatori.

Il quarto capitolo estende l'analisi dei sistemi integrati in una valutazione ad ampio spettro compiuta sulla possibilità di risparmio energetico connesse al rinnovamento del parco residenziale Europeo. L'analisi ha valutato la composizione e la distribuzione delle tipologie edilizie sul territorio europeo, individuando quattro casi studio, edifici tipo, sui quali compiere le successive valutazioni. Le prestazioni energetiche dei casi studio sono state valutate in relazione al loro stato precedente e successivo ad una completa ristrutturazione dell'involucro edilizio e degli impianti tecnici. L'analisi é stata nuovamente operata per mezzo di una serie di simulazioni dinamiche in ambiente TRNSYS, mirate a valutare il possibile risparmio energetico legato alla riqualificazione dei casi studio in edifici a basso consumo energetico (LEB, Low Energy building). Allo scopo di garantire allo studio una prospettiva di carattere europeo,l'analisi é stata ripetuta e rimodulata per diversi climi: sono stati individuati quattro siti, caratterizzati da condizioni climatiche molto diverse tra loro, rispettivamente Budapest, Venezia, Atene e Helsinki.

TABLE OF CONTENTS

CHAPTER

1

EUROPEAN STRATEGIES TOWARD THE INCREASE OF THE ENERGY EFFICIENCY IN BUILDINGS.

Abstract

One of the primary European Union's "Europe 2020" energy strategy is the reduction of the total energy consumption by the means of energy efficiency improvements. In European Union (EU) the building sector is responsible of about the 40% of the total final energy consumption and of the 36% of the Europe global CO_2 emissions. During the last decade the European Commission released the first legislative instrument aimed to improve the energy performance of buildings: the "Energy Performance of Building Directive" (EPBD) was introduced in the 2002 and updated in the 2010.
The first edition of the document focused the analysis on new building, in order to promote the diffusion of energy efficient buildings, characterized by very low energy demand, possibly almost zero energy building. The recast of the document introduces the important topic of the existing building stock. The renovation of the existing building stock and the improvement of the energy performances are expected to have a key role in the increasing of European energy efficiency as well, considering that the average annual rate for the construction of new dwelling within the EU-15 member states is about 1% and the replace rate is the 0.07% of the existing stock. The esteems sets that only the 25% of the buildings that will exist in the 2050 haven't already to be built, that means that the 75% of the future stock is already existing.
This chapter introduces the topic of the energy efficiency in building, presents and discuss the recommendations that the European Commission released so far and focused on the possibilities of increasing the energy efficiency of building according to feasible retrofit strategies.
An overview of the European building stock is provided, in order to comprehend the magnitude of the issue. The composition and the age of the existent building are analyzed as well as the actual energy consumption according to the final uses. Base on the described situation the requirements introduced by the EPBD are analyzed according to new and existent buildings.

1.1 Introduction

The European Union (EU) aims at drastic reductions in domestic greenhouse gas emissions (GHG) by 80% in 2050 compared to 1990 level [1]. One of the primary European Union's "Europe 2020" energy strategy is the reduction of the total energy consumption by the means of energy efficiency improvements.

It is widely known that in European Union (EU) the building sector is responsible of about the 40% of the total final energy consumption, and that the 36% of the Europe global CO_2 emissions are imputable to existing buildings. During the last decade the European Commission released the first legislative instrument aimed to improve the energy performance of buildings: the "Energy Performance of Building Directive (EPBD) was introduced in the 2002 and updated in the 2010. [2]
The recast Directive on the energy performance of buildings (EPBD) asses that by 2020 all new buildings constructed within the European Union should reach nearly zero energy levels. This means that in less than one decade, all new buildings have to guarantee very high energy performance. moreover their low energy needs have to be significantly covered by renewable energy sources.
The reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute the two important achievements which are needed to reduce energy dependency and greenhouse gas emissions.
Considering the variety in building culture and climate throughout Europe, the Energy Performance of Buildings Directive requires EU Member States to elaborate national definitions and to design national road map toward nearly Zero-Energy Buildings, reflecting specific national and regional conditions. More than one quarter of the 2050 building stock is still to be built and consequently more efforts are needed for supporting the effective implementation of low energy buildings across Europe by providing guidance, common principles and quality checks of the concepts. A sustainable, robust and feasible country definitions and EU standards to support the successful implementation of the Directive are fundamental for realizing the forecast savings potential and for maximizing the socio-economic benefits. The move towards very low-energy buildings is expecting to generate a deep transformation of the construction sector and to cause an important growth to the market of very efficient technologies. This market up-scaling presents important employment potential considering the jobs that can be created and induced across Europe [1].
The European Union (EU) aims at drastic reductions in domestic greenhouse gas (GHG) emissions of 80% by 2050 compared to 1990 levels. The building stock is responsible for a major share of GHG emissions and should achieve even higher reductions of at least 88% - 91%i. Therefore, without consequently exploiting the huge savings potential attributed to the building stock, the EU will miss its reduction targets. More than one quarter of the 2050s building stock is still to be built. The energy consumption and related GHG emissions of those new buildings need to be close to zero in order to reach the EU's highly ambitious targets.
Beside the recommendations on new building the EPDB highlights also that the renovation of the existing building stock and the improvement of its energy performances are expected to have a key role in the increasing of European energy efficiency, considering the fact that the average annual rate for the construction of new dwelling within the EU-15 member states is about 1% and the replace rate is the 0,07% of the existing stock. The esteems sets that only the 25% of the buildings that will exist in the 2050 haven't already to be built, that means that the 75% of the future stock has already be built.

1.2 The EPDB recast

The recast of the Energy Performance of Buildings Directive (EPBD) introduced, in Article 9, "nearly Zero -Energy Buildings" (nZEB) as a future requirement to be implemented from 2019 onwards for public buildings and from 2021 onwards for all new buildings. The EPBD defines a nearly Zero-Energy Building as follows: [A nearly Zero-Energy Building is a] "*building that has a very high energy performance… [ ]. The nearly zero or very low amount of energy required should to a very* *significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby."*

The Major Highlights of the Recast Directive include:

- There is no specific target be set for the renovation of existing building, but Member States shall developing policies and take measures such as targets in order to stimulate the transformation of buildings that are refurbished into very low energy buildings
- The 1000 m^2 threshold for major renovation, present in the first edition of the document, has been deleted and this will take effect when the national regulations have been implemented and applied, probably at the beginning of 2014.
- Minimum requirements for components are introduced for all replacements and renovations, although for major renovations, the holistic calculation methodology is the preferred method with performance calculations based on component requirements allowed as a complement or alternatively
- A more detailed and rigorous procedure for issuing energy performance certificates will be required and control systems will be required to check the correctness of performance certification.
- Member States will be required to introduce penalties for non-compliance, they must be effective, proportionate and dissuasive.

The EPBD does not prescribe a uniform approach for implementing nearly Zero-Energy Buildings and neither does it describe a calculation methodology for the energy balance. To add flexibility, it requires Member States to draw up specifically designed national plans for increasing the number of nearly Zero-Energy Buildings reflecting national, regional or local conditions. The national plans will have to translate the concept of nearly Zero -Energy Buildings into practical and applicable measures and definitions to steadily increase the number of nearly Zero-Energy Buildings.

The loss of a clear nZEB definition leaves room for interpretation and the flexibility of the EPBD definition arises some questions:

- how to keep the nZEB definition sufficiently flexible so as to build upon existing low-energy standards
- how to enable energy-positive buildings
- how to properly define and set the share of renewable energy
- how to determine the optimal balance between energy efficiency and renewable energy
- how to link the nZEB definition to cost-optimality principles in order to have convergence and continuity

At the present moment, the European Commission, EU Member States, stakeholders and experts are discussing the different aspects of nZEBs. Overall, there is an urgent need to establish common principles and methods to be taken into account by EU Member States for elaborating effective, practical and well thought-out nZEB definitions.

Throughout Europe there is a large variety of definitions and voluntary standards for highly energy efficient buildings or even climate neutral buildings, like as: passive house, zero-energy, 3-litre, plus energy, Minergie, Effinergie etc. In addition, these definitions refer to different entities: site energy, source energy, cost or emissions. Moreover there are several variations in the requirements of the above standards depending on whether new or existing, residential or non-residential buildings are under consideration.

Typically, low-energy buildings needs to have a high level of insulation, very energy efficient windows, a high level of air tightness and natural/mechanical ventilation system with very efficient heat recovery to reduce heating/cooling needs. In addition, other energy/resource saving measures may also be utilized, like as solar thermal collectors, photovoltaic systems, on-site windmills to produce electricity or rainwater collecting systems.

Today, more than half of the Member States do not have an officially recognized definition for low or Zero-Energy Buildings, but various Member States have already set up long-term strategies and targets for achieving low-energy standards for new houses. Some of them presents common approaches but also significant differences. Aggregation and improvement of the existing concepts is needed in order to align them to the nearly Zero-Energy Buildings requirements indicated by the EPBD and the Renewable Energy Directive.

Three main issues to be considered as the existing low-energy buildings definitions evolve towards a nearly Zero-Energy Building definition have to be highlighted:

- Most of the low-energy building definitions in the European countries specify a maximum percentage of their national building standards' limit for primary energy consumption per square meter and year. However, there are variations between EU Member States on how to calculate and express the primary energy consumption of a building (for example using net or gross floor areas).
- The existing low-energy building definitions do not specifically indicate a certain share of renewable in the energy supply. The EPBD Recast indicates that energy required should be covered to a significant extent by renewable sources. Especially this lack of guidance on the share of renewable resources generates a mismatch between current regulations or definitions and the above-cited EPBD nearly zero-energy definition.
- There are various elements of existing concepts that can be used for the development of a nearly Zero- Energy Building definition, such as the principle of working with overarching targets accompanied by "sub-thresholds" on specific issues (such as requirements for maximum primary energy demand and additional limits for heating energy demand within the passive house concept).
- These problems should be resolved in order to achieve a common and homogeneous definition of Low/Zero energy buildings.

1.3 Low Energy Buildings In Europe: Current State of definition and costs

The proposal for a recast of the Directive on the energy performance of buildings (EPBD) suggests that all EU Member States (MS) endorse national plans and targets in order to promote the uptake of very low and close to zero energy buildings. In low energy buildings, as much as 80% of the operational costs can be saved through integrated design solutions; however there is still a limited market uptake [3].

The present paragraph is supposed to provide background information regarding definitions, calculation methods and MS policies in Europe. Like it has been already said there is no global definition for low-energy buildings, but it generally indicates a building that has a better energy performance than the standard alternative/energy efficiency requirements in building codes. Low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation to lower heating and cooling energy. They may also use

passive solar building design techniques or active solar technologies. These homes may also use hot water heat recycling technologies to recover heat from showers and dishwashers.
In fact, low energy buildings are known under different names across Europe. A survey carried out in 2008 by the Concerted Action supporting EPBD identified different terms in use to describe such buildings used across Europe, among which the terms low energy house, high-performance house, passive house/Passivhaus, zero carbon house, zero energy house, energy savings house, energy positive house, 3-litre house etc.
Variations exist not only as regards the terms chosen, but also what energy use is included in the definition. Ideally, the minimum performance requirements should take into account all types of energy use that is demand for space heating (cooling), water heating, air conditioning as well as consumption of electricity. This is often not the case. On the contrary, the definition may cover only space heating ignoring all electricity demand that may cover most heating needs for instance in office buildings.
At present, seven EU MS have defined for themselves when a building is a low energy building (AT, CZ, DK, UK, FI, FR and DE, BE (Flanders), a few more (LUX, RO, SK, SE) plan to do so. Definitions typically target new buildings, but in some cases (AT, CZ, DK, DE, LUX) also cover existing buildings and apply in almost all cases to both residential and nonresidential buildings. Typically the required decrease in energy consumption will range from 30 to 50 % of what is defined for standard technology for new buildings. That would generally correspond to an annual energy demand of 40- 60 kWh/m² in Central European countries. Given the varying climatic and regulatory conditions across Europe, it is difficult to define exactly the concept of low energy building for the entire EU. National standards and methodologies vary so that 'low energy' developments in one country may not meet 'normal practice' in another [3].
The cost of building energy efficient is generally higher due to the extra costs associated with improved insulation of all building components such as windows. Another reason is that most entrepreneurs are not used to the new technologies and much time and resources are invested in planning, education and quality assurance – which bring up costs. This has also contributed to the idea that energy-efficient buildings are expensive. Exact information on these additional costs were difficult to find, in particular for countries with less developed low energy markets, but this chapter gives an overview of studies and the situation in several countries.
Indeed it can be shown that in Germany, Austria or Sweden it is now possible to construct Almost zero energy buildings for costs that are no longer significantly higher than for normal standards because of increasing competition in the supply of the specifically designed and standardized building products. For these countries the extra cost of construction is generally indicated to be in the range of 4-6 % more than for the standard alternative.
The Passive-On project estimates the range of additional upfront costs across five involved countries (UK, FR, PT, ES, IT) to be in the range of 3-10 % for newly constructed buildings respecting passive house standards. The cost difference between a low energy and the more ambitious passive house standard is indicated with 8 % (around 15.000 Euro) for Germany.
For the specific case of Passive house buildings, it should be noted that buildings bring a substantial reduction of total costs at around 15kWh/m² p.a., point at which a traditional heating system is no longer needed. If a house is built as a passive house, one can actually save money for not having to install a radiator system at all. At this level of energy efficiency, the gains form energy savings will also be significant. However One should be cautious in trying to transfer cost estimations from one country to another, as energy prices, labor cost, available experience and expertise differ significantly, as does the way in which each construction project is executed. In particular, it seems misleading to

try to transfer the price estimations from countries which are already in their phase of rapid spread (Germany, Austria) to other countries where low energy buildings are not yet common (East and some southern European countries).
However, in general, the additional investment will be in the range of 100 EUR/m² (more if expensive solutions are used) with returns of less than 20 years. Costs are expected to further decrease in the future due to technological developments and it was assumed that they would decrease by 20% by 2030. Low energy buildings offer considerable savings in energy bills over their lifetime compared to standard new constructions as they basically only use 15–25 % of the energy required to run a conventional one [3].

1.4 Benchmarks for nearly zero-energy buildings, suggestion for a suitable definition

The necessity to compare the results and the methodology for low energy building around Europe requires quality and quantity parameters of comparison. Numeric benchmarks are most useful when the values to be compared with these benchmarks result from transparent and ideally identical calculation methodologies. Therefore the development of an explicit methodology for analyzing building in terms of energy performance and global costs it is necessary, in order to detailing the inputs and assumptions made and for clearly reporting the results obtained. The main objective is to support Member States in transparently expressing the meaning and ambition level of requirements for nearly zero-energy buildings for different climates and building types.
Member States should ensure that good quality data are available, including:

- Climate data matching the minimum quality specified in EN standards, ideally on a grid of a few kilometers space and both based on recent measurements and on forecasts of future weather evolution
- Cost data for building components, explicitly and clearly correlated to their physical and performance features; analysis of potential technological and cost evolution of main components.

In principle, benchmarks could be set without deriving them on any sophisticated calculation or related cost. Yet, verifying whether an energy and comfort benchmark is met or not requires transparent and accurate definitions and calculations (or measurement). Global costs over the lifetime of the building are an important parameter both for private investors and for decision makers. Therefore, we chose to follow the cost-optimal methodology (as laid down in Commission Regulation 244/2012 and accompanying guidelines[4]) for developing these benchmarks, in line with the tender requirement.
The terminology used, and recommended for use in the formulation of the Member States' plans for increasing the number of nearly zero-energy buildings, is the one defined in EN standards, i.e. EN 15603:2008 “Energy performance of buildings - Overall energy use and definition of energy ratings” [5] and the technical report CEN/TR 15615 “Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) - Umbrella Document” [6]. In particular it is important to be fully aware of the definitions for *a) energy need, b) energy use, c) delivered energy* and *d) primary energy* in order to fully grasp the proposed methodology for calculation and presentation of results.
From EPBD definitions given in Article 2, 9 and Annex I, it follows that:

a) Member States have to choose *an energy performance indicator* (which can be chosen e.g. at the level of energy need for heating, cooling and hot water plus energy use for lighting, and/or delivered energy, and/or embedded energy,, and/or load match with the grid,...) and a numeric indicator of primary energy use;

b) The time interval over which to calculate the performance may be a year but shorter sub-indicators that might be used to evaluate energy performance as described in Annex I.

This seems to imply that Member States can determine their own "detailed application in practice of the definition" by choosing - for the primary energy balance - among different nearly zero-energy building definition *families* and additional indicators next to primary energy per year. As such, they may use a different calculation time interval from a year, which is especially useful for analyzing the interaction of the building with the electricity grid and other energy grids.

From this analysis it appears that a useful way to establish a low energy building definition might include all of the following elements:

A) A performance part and a prescriptive part on energy needs and energy use.[3] Energy needs for heating, cooling and hot water and energy use for lighting (and optionally energy use for ventilation, auxiliaries and plug loads) are based only on physical variables and the choice of thermal and visual comfort set points and hence do not require any weighting factors (performance part). Additionally, a prescriptive approach might indicate minimum requirements for *components* (e.g. U-values for windows and walls, g-values for solar protections, air tightness, (built-in) lighting installations) etc. Domestic hot water use is highly dependent on occupant density in a building unit. Therefore specific values are more difficult to establish than for heating and cooling, and should be derived from typical national occupant densities and on typical national per capita water use. Today, specific DHW use equals (single family home) or even exceeds (multi family home) space heating or space cooling needs of e.g. passive houses. With a view to 2020 and beyond, the reduction of DHW needs has to be seriously addressed, e.g. by applying low flow shower heads or faucets and/or heat recovery. As for lighting in non residential buildings, careful design of the envelope can maximize daylight availability; reduction of distance of light sources from task areas, use of efficient sources and luminaries, daylight and occupancy controls with low stand-by power may enable very good visual comfort with relatively low annual energy use. In the medium term, targets for lighting in residential buildings as well as appliances and plug-loads could be added, including e.g. refrigerators, washing machines, dishwashers, etc.

B) A yearly weighted primary energy balance defined as in EN 15603:2008 - preferably also showing monthly or shorter time intervals. Transparency of the calculation methodology and how primary energy factors are derived is fundamental. If relevant, especially in the case of electricity, the weighting may take into account the sources' actual input to the grid, or even additional factors such as related pollution, impact on the grid, etc. In case a load match index (see below) is not used, a proxy way to take this into account may be to choose a different (lower) primary energy conversion factor for energy exported to the grid in case of on-site generation, although being considerably less precise and thus less preferable than a load match index. In the long term, with a view to longer-term climate targets, primary energy might be supplemented with a comprehensive "total emissions" measure including greenhouse gas emissions, acidification, ozone depletion, particulate matter, nuclear waste etc.

C) A value that illustrates the real share of energy from renewable sources. Although being partially integrated in the previous two elements *implicitly*, in the light of the EPBD definition for nearly zero-energy buildings this value should be made *explicit*. The main issues to be solved are clear definitions of temporal and spatial boundaries and avoidance of double counting especially for electricity from renewable sources. Here the interaction of the building and on-site generation from PV with the grid should be quantified by means of e.g. a "load matching index" or other similar indices – in the end

showing the share of self-consumed locally generated renewable electricity - calculated with time steps of a month , day or (preferably) hour. In the presence of smart meters and smart grids, and the on-going quick reduction of costs of meters and data transfer, metering of generated and exported energy in little time steps and calculation of the load match index seem to cause small investments.
D) One or more long-term comfort indices calculated according to EN 15251 [7] or other relevant literature, because *"an energy declaration without a comfort declaration makes no sense* . IEA Annex 52 "Towards Net Zero Energy Solar Buildings" has analyzed and proposed methodologies for incorporating comfort indexes in the characterization of zero energy buildings[5]. In any case, energy-related benchmarks for nearly zero buildings must include the underlying comfort level explicitly and quantified. Buildings with low energy needs have additional benefits usually neglected, underrated or at least not explicitly mentioned: more uniform temperature distribution, less draughts, higher availability of day lighting (if energy for lighting has been accurately taken into account), etc. In a nutshell: generally higher thermal and visual comfort and better use of valuable floor space.

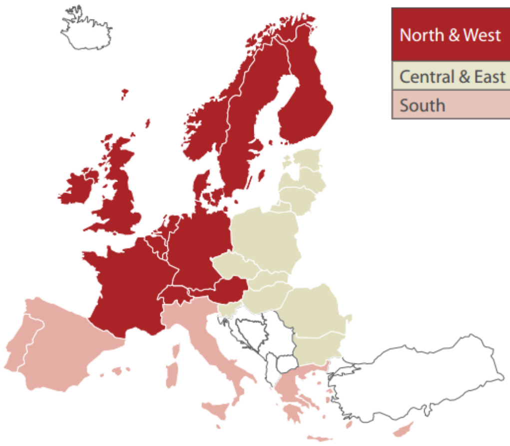
1.5 The European Residential building Stock[1]

1.5.1 Composition And Energy Consumption

Buildings occupy a key place in our lives and society. Yet, the energy performance of our buildings is generally so poor that the levels of energy consumed in buildings place the sector among the most significant CO^2 emissions sources in Europe. While new buildings can be constructed with high performance levels, it is the older buildings, representing the vast majority of the building stock, which are predominantly of low energy performance and subsequently in need of renovation work. With their potential to deliver high energy and CO_2 savings as well as many societal benefits, energy efficient buildings can have a pivotal role in a sustainable future.
Achieving the energy savings in buildings is a complex process. Policy making in this field requires a meaningful understanding of several characteristics of the building stock. Reducing the energy demand requires the deployment of effective policies which in turn makes it necessary to understand what affects people's decision making processes, the key characteristics of the building stock, the impact of current policies etc.
It is estimated that there are 25 billion m^2 of useful floor space in the EU27, Switzerland and Norway. The gross floor space could be concentrated in a land area equivalent to that of Belgium (30,528 km^2) (Figure 1.1). Half of the total estimated floor space is located in the North & West region of Europe while the remaining 36% and 14% are contained in the South and Central & East regions, respectively1[2]. Annual growth rates in the residential sector are around 1% while most countries encountered a decrease in the rate of new build in the recent years, reflecting the impact of the current financial crisis on the construction sector.
Non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector (Figure 1.2). The retail and wholesale buildings comprise the largest portion of the non-residential stock while office buildings are the second biggest category with a floor space corresponding to one quarter of the total non-residential floor space. Variations in usage pattern (e.g. warehouse versus schools), energy intensity (e.g. surgery

[1] Data and considerations of this paragraph are derived from the document Europe's Buildings Under The Microscope published by the Buildings Performance Institute Europe (BPIE), 2011

rooms in hospitals versus to storage rooms in retail), and construction techniques (e.g. supermarket versus office buildings) are some of the factors adding to the complexity of the sector.
Space standards (expressed through the floor area per capita) are the highest in countries in the North & West while the countries of Central & Eastern Europe have the lowest residential space standards



North & West	AT, BE, CH, DE, DK, FI, FR, IE, LU, NL, NO, SE, UK	Population: 281 mil
Central & East	BG, CZ, EE, HU, LT, LV, PL, RO, SI, SK	Population: 102 mil
South	CY, GR, ES, IT, MT, PT	Population: 129 mil

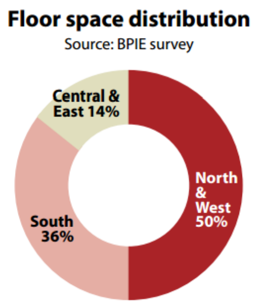


Figure 1.1. Countries and regions considered with equivalent population and floor space. (BPIE survey)

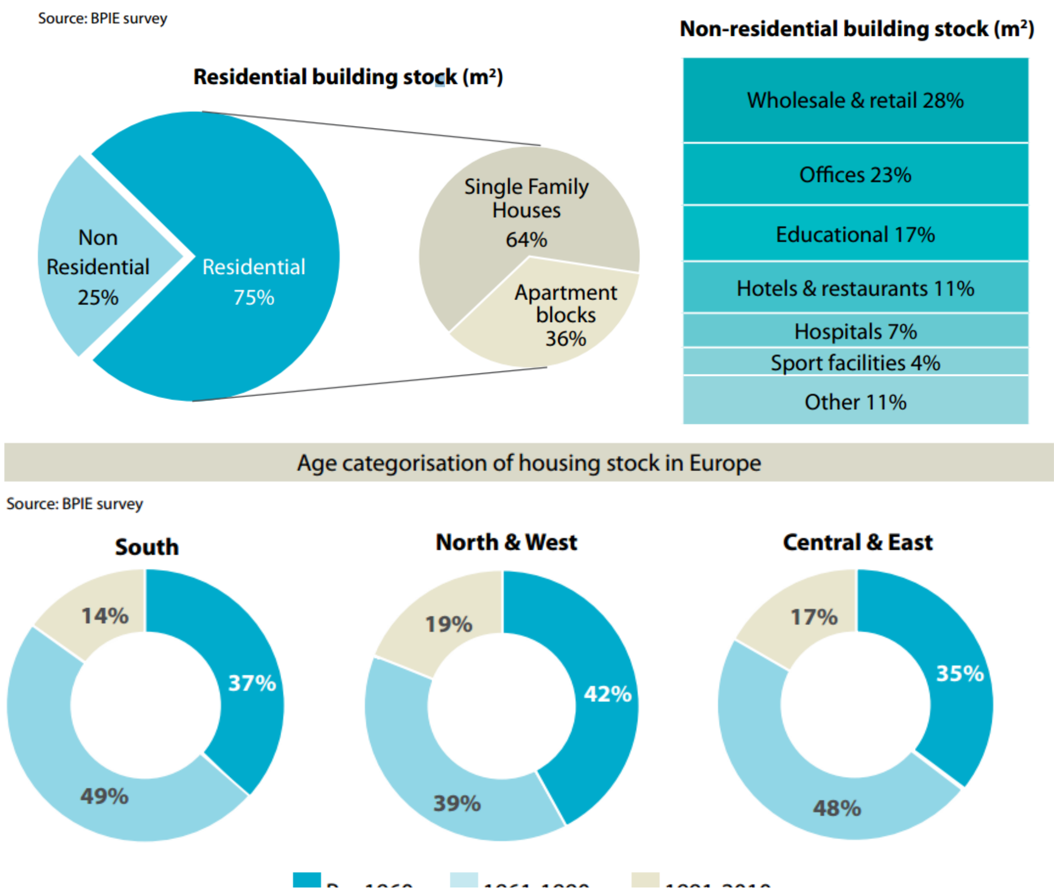


Figure 1.2. European buildings overlook

Both in single family houses and apartment blocks. Economic wealth, culture, climate, scale of commerce, increased demand for single occupancy housing are some of the factors affecting the size of spaces we live and work in. The general tendency however is to seek larger floor spaces over time. This along with the increasing population projections has clear implications on future energy needs, emphasizing the subsequent urgency for improving the energy performance of our buildings.

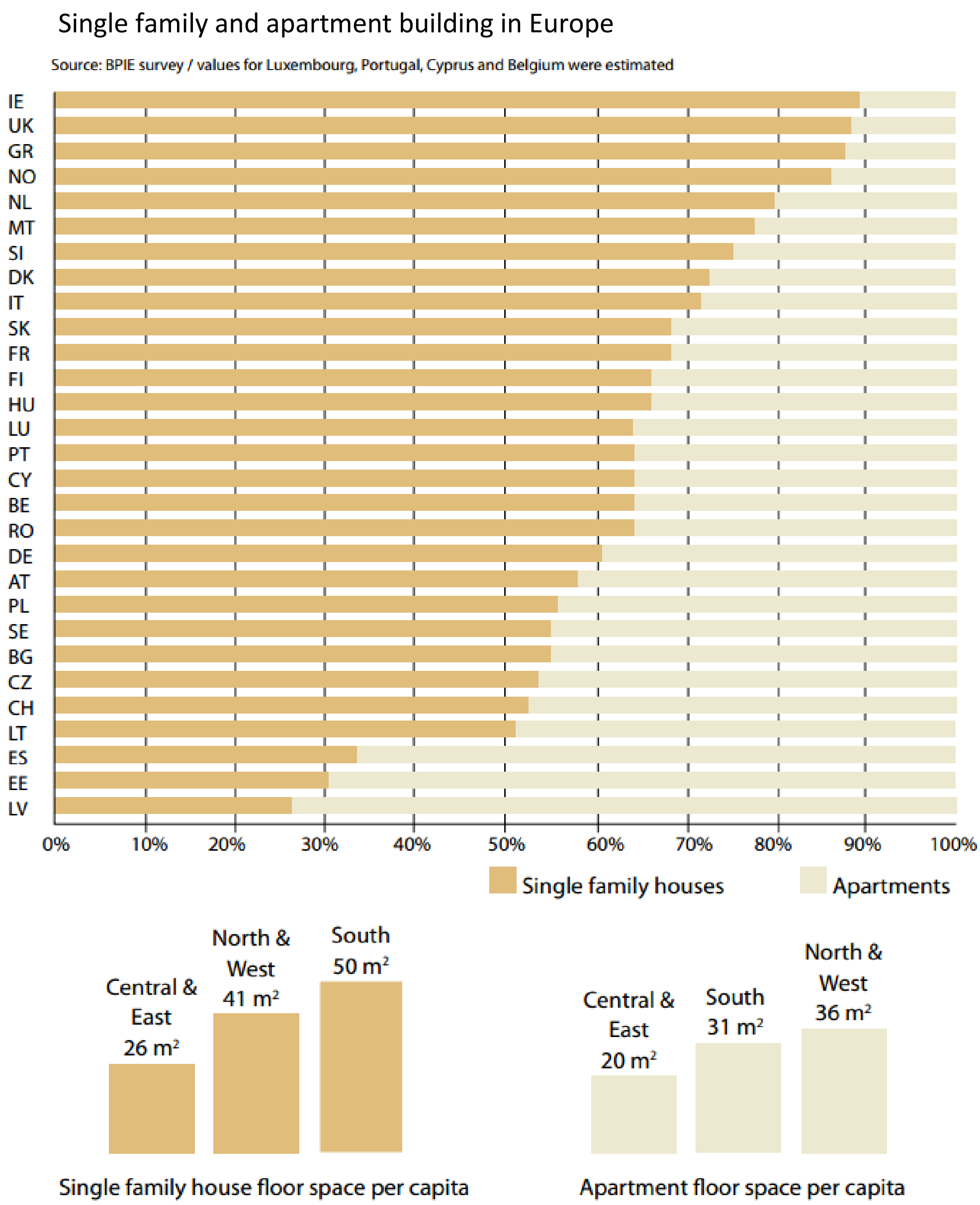


Figure 1.3. Composition and dimensions of European dwellings

A substantial share of the stock in Europe is older than 50 years with many buildings in use today that are hundreds of years old (Figure 1.2). More than 40% of our residential buildings have been constructed before the 1960s when energy building regulations were very limited. Countries with the largest components of older buildings include the UK, Denmark, Sweden, France, Czech Republic and

Bulgaria. A large boom in construction in 1961-1990 is also evident through our analysis where the housing stock, with a few exceptions, more than doubles in this period. The performance of buildings depends on a number of factors such as the performance of the installed heating system and building envelope, climatic conditions, behavior characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty). Data on typical heating consumption levels of the existing stock by age shows that the largest energy saving potential is associated with the older building stock where in some cases buildings from the 1960s are worse than buildings from earlier decades. The lack of sufficient insulation of the building envelope in older buildings was also reflected through the historic U-value data which comes with no surprise as insulation standards in those construction years were limited.

The building sector is one of the key consumers of energy in Europe where energy use in buildings has seen overall a rising trend over the past 20 years. In 2009, European households were responsible for 68% of the total final energy use in buildings[3]. Energy in households is mainly consumed by heating, cooling, hot water, cooking and appliances where the dominant energy end- use (responsible for around 70%) in homes is space heating. Gas is the most common fuel used in buildings while oil use is highest in North & West Europe. The highest use of coal in the residential sector is in Central & Eastern Europe where also district heating has the highest share of all regions. Renewable energy sources (solar heat, biomass, geothermal and wastes) have a share of 21%, 12% and 9% in total final consumption in Central & Eastern, South and North & West regions, respectively (Figure 1.4).

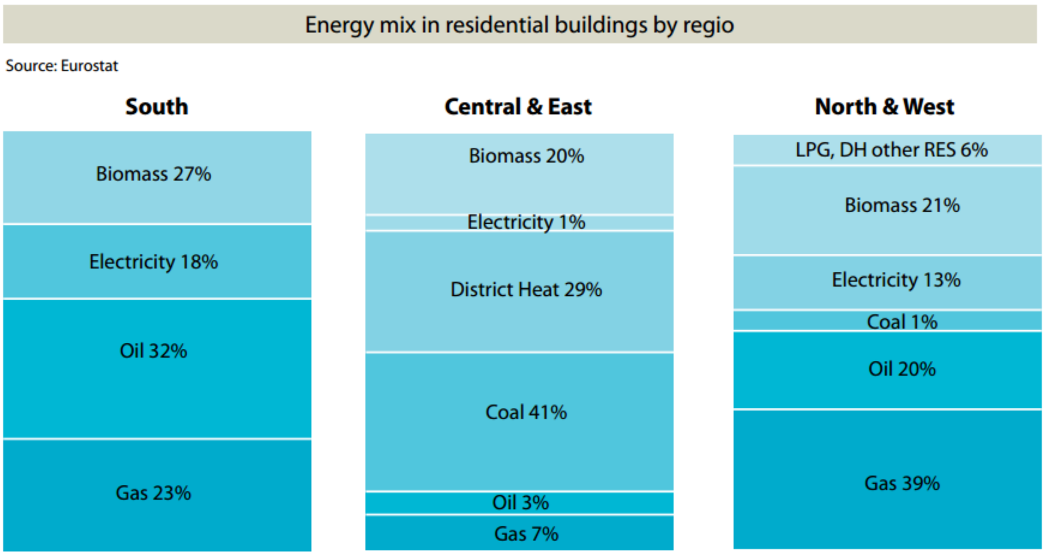


Figure 1.4. Energy consumption for end-uses

The average specific energy consumption in the non residential sector is 280 kWh/m^2 (covering all end uses) which is at least 40% greater than the equivalent value fort the residential sector. In the non residential sector, electricity use over the last 20 years has increased by a 74%. Buildings vary remarkably in terms of size where large variations are expected in the non-residential categories. From our data, we can see that policy measures applied only to non-residential buildings over 1,000 m^2 in floor area would miss a substantial portion of buildings in many countries, especially in educational buildings, hospitals and offices.

[3] Data extracted from Eurostat: http://epp.eurostat.ec.europa.eu

The structure of ownership and occupancy has also a significant relevance on the ability to renovate. The largest share of the residential stock is held in private ownership while 20% is allocated to 'pure' public ownership. Social housing is typically fully owned by the public sector but there is an increasing trend towards private involvement as is the case in Ireland, England, Austria, France and Denmark while in the Netherlands social housing is fully owned by private sector. Moreover, at least 50% of residential buildings are occupied by the owner in all countries. Countries with the biggest share of private tenants are Switzerland, Greece and Czech Republic and countries with significant portions of public rented dwellings are Austria, the UK, Czech Republic, The Netherlands and France. The ownership profile in the non-residential sector is more heterogeneous and private ownership can span from as low as 20% to 90% from country to country.

1.5.2 Building Energy Codes in Europe

At the European level, the main policy driver related to the energy use in buildings is the Energy Performance of Buildings Directive (EPBD, 2002/91/EC). Implemented in 2002, the Directive has been recast in 2010 (EPBD recast, 2010/31/EU) with more ambitious provisions. Through the EPBD introduction, requirements for certification, inspections, training or renovation are now imposed in Member States prior to which there were very few. While all countries now have functional energy performance certification (EPC) schemes in place, five countries have not yet fully implemented the scheme for all requested types of buildings. Only eleven countries currently have national EPC register databases while ten countries have databases at regional/local level or development plans underway. Data on the number of issued EPCs show that the current share of dwellings with an issued EPC in different countries can vary from under 1% to just above 24%. The absence of previous requirements in most Member States meant that entirely new legislative vehicles were required and consequently that the first EPBD was typically implemented in stages over a number of years, from around 2006 to 2010.

Despite the fact that significant developments happened over the last years, current EU legislation only partially covers the field of buildings renovation. The EPBD stipulates the implementation of energy saving measures only in case of deep renovation of the building without specifying the depth of renovation measures. It is clear that more targeted measures are required for fostering the deep renovation of the existing building stock.

A key driver for implementing energy efficiency measures are the building energy codes, through which energy-related requirements are incorporated during the design or retrofit phase of a building. While several Member States had some form of minimum requirements for thermal performance of building envelopes in the 1970s, the EPBD was the first major attempt requiring all Member States to introduce a general framework for setting building energy code requirements based on a "whole building" approach. Examining the requirements set by each Member State, it is clear that large variations exist in terms of the approach each country has taken in applying building energy codes. In some countries two approaches exist in parallel, one based on the whole building approach and the other one on the performance of single elements. In others, the single element requirements act as supplementary demands to the whole building approach. In some cases the requirements for renovating buildings can be as ambitious as the new build requirements. Major changes are expected through the application of the cost-optimality concept in energy performance requirements as introduced by the recast EPBD which should also gradually converge to nearly zero energy standards, a requirement for new buildings from 2020 onwards. An appropriate level of enforcement compliance with building energy codes should also be of concern and a point of attention for policy makers as it is

necessary to ensure that enough rigor and attention to detail are undertaken when applying energy efficiency measures.
Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow[4]. Buildings are intrinsically linked to Europe's societies, Europe's economies, and their future evolution. Energy security and climate change are driving a future that must show a dramatic improvement in the energy performance in Europe's buildings. The 27 Member States have set an energy savings target of 20% by 2020, mainly through energy efficiency measures. The European Union has also committed to 80-95 % GHG reduction by 2050 as part of its roadmap for moving to a competitive low-carbon economy in 2050[5] .Buildings currently represent almost 40% of total final energy consumption and, therefore, can make a crucial contribution to these targets. In the Energy Efficiency Plan 2011[6], the European Commission states that the greatest energy saving potential lies in buildings. The minimum energy savings in buildings can generate a reduction of 60-80 Mtoe/a[7] in final energy consumption by 2020, and make a considerable contribution to the reduction of GHG emissions. This will be achievable only if buildings are transformed through a comprehensive, rigorous and sustainable approach.
The European policy framework for buildings has been evolving since the early 1990s. A wide array of measures has been adopted across individual Member States to actively promote the better energy performance of buildings. After 2002, the issue gained strong momentum when the Directive on Energy Performance of Buildings (EPBD) [Directive 2002/91/EC] was adopted. The EPBD was recast in 2010 to make the goals more ambitious and to reinforce the implementation.
The European Union stretches over many different climate zones, landscapes and cultures. Some 501 million inhabitants spread over 27 countries 7 reside in a wide array of building types with an equally wide range of thermal qualities, in a constantly expanding building stock. From styles of living – single-family dwellings or multi-family dwellings, for example – to policies for the construction of buildings, there are significant differences between countries. National approaches to monitoring the building stock have also evolved separately. Information is not only needed to track the progress of policy implementation, better information and data are required to help develop a European pathway and roadmaps to more energy efficient buildings. In order to define the energy and CO2 reduction potential, we need to study and evaluate the technical and economic opportunities, feasibilities and limits. Indeed, it is a major obstacle to strong policy making at EU level that there is a lack of data on the building sector for Europe as a whole.
The energy performance of buildings evolve and become more complex, policy makers need more concrete and precise facts to be able to make cross-country comparisons and to put in place the monitoring systems that permit measurement of the progress of the various policy instruments.
In terms of growth, annual rates in the residential sector are around 1% as depicted in Figure 1.6, which shows the range of new build rates in the residential countries for a range of countries over the period between 2005 and 2010.

[4] Paul Hawken - The HOK Guidebook to Sustainable Design
[5] Directive 2010/31 of the European Parliament and of the Council of 17 May 2010 on the energy performance of buildings and its amendments (the recast Directive entered into force in July 2010, but the repeal of the current Directive will only take place on 1/02/2012).
[6] Energy Efficiency Plan 2011, Communication from the commission to the European Parliament, the council, the European economic and social Committee and the committee of the regions, European Commission, 2011
[7] Summary of the impact assessment accompanying document to the proposal for a recast of the energy performance of buildings directive (2002/91/EC).

There has been significant Europe-wide legislation on buildings and there are several forthcoming initiatives underway to improve the energy performance of new and existing buildings. Yet, much of this is done with only a minimum of fact-based knowledge, analysis and evidence. As strategies for Except The Netherlands (in the case of multi-family houses), all other countries experienced a decrease in the rate of new build in recent years, reflecting the impact of the current financial crisis in the construction sector. Notably, this impact seems to be more pronounced in countries in Central & Eastern Europe as is the case in Latvia, Romania and Poland.

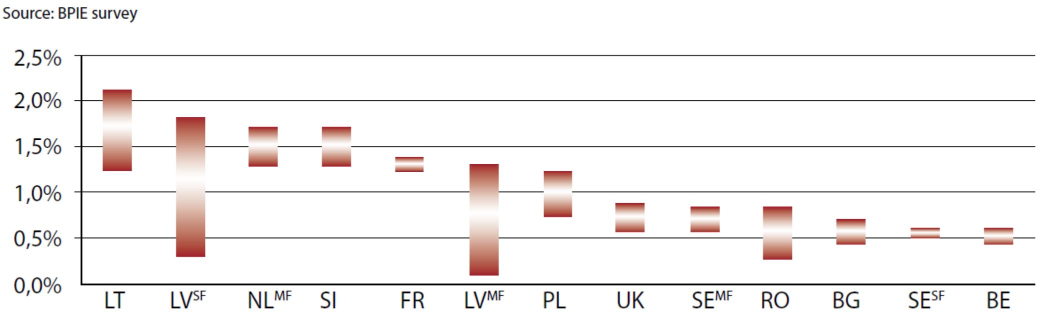


Figure 1.5. Range of new build rates in the residential sector (2005-2010) where SF and MF denote single family and multi-family houses, respectively.

1.5.3 Energy performance of buildings

It is widely recognized that the building sector is one of the key consumers of energy in Europe[8]. Understanding energy consumption in buildings requires an insight into the energy levels consumed over the years and the mix of fuels used. Figure 1.6 shows the historical final energy consumption in buildings in EU27, Norway and Switzerland since the 1990s. The consumption is made up of two main trends: a 50% increase in electricity and gas use and a decrease in use of oil and solid fuels by 27% and 75%, respectively. Overall, the energy use in buildings is a rising trend with an increase from around 400 Mtoe to 450 Mtoe over the last 20 years. This is likely to continue if insufficient action is taken to improve the performance of buildings. In terms of CO_2 emissions, buildings are responsible for around 36% in Europe.

The average specific CO_2 emission15 in Europe is 54 $kgCO_2/m2$ where the national values of $kgCO_2$ per floor space vary in the range from 5-120 $kgCO_2/m2$ as shown in Figure 1.7. The building performance is a key component in this. In addition, CO_2 emissions are linked to the particular energy mix used in buildings in a given country. For example, the extent to which renewable energy is employed in the buildings, the use of district heating and co-generation, the sources of electricity production in each country affect the CO_2 emissions related to buildings. Variations in the energy supply mix highly influence the CO_2 performance of buildings where, for instance, Norway and France are among the lowest in Europe as shown in Figure 1.7 due to their dependence on hydroelectricity and nuclear energy, respectively.

[8] Data extracted from Eurostat: http://epp.eurostat.ec.europa.eu

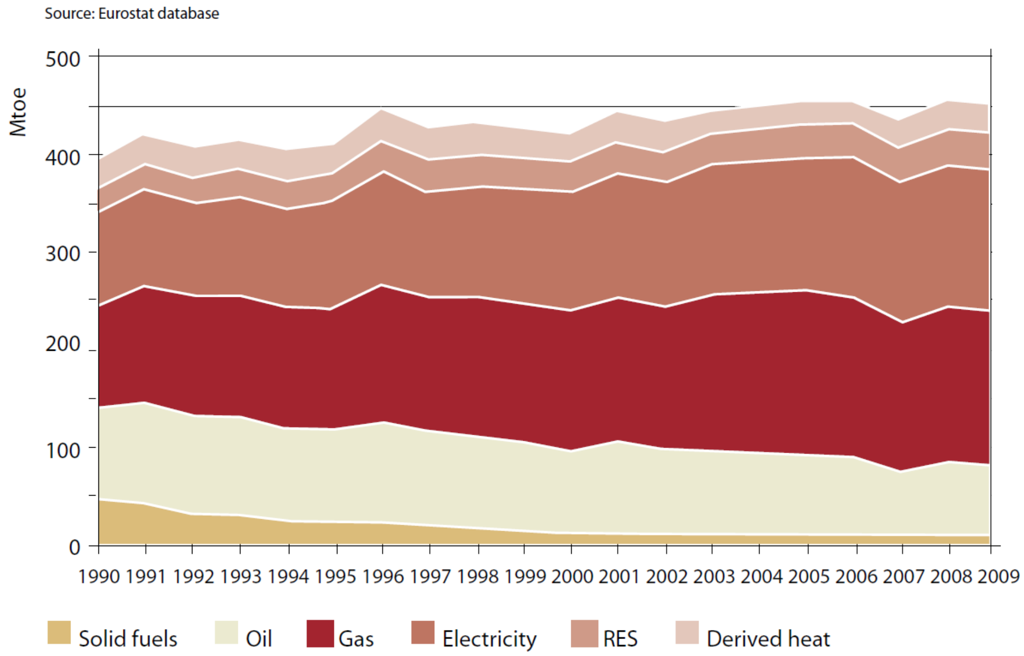


Figure 1.6. Historical final energy consumption in the building sector since 1990s for the EU27, Switzerland and Norway

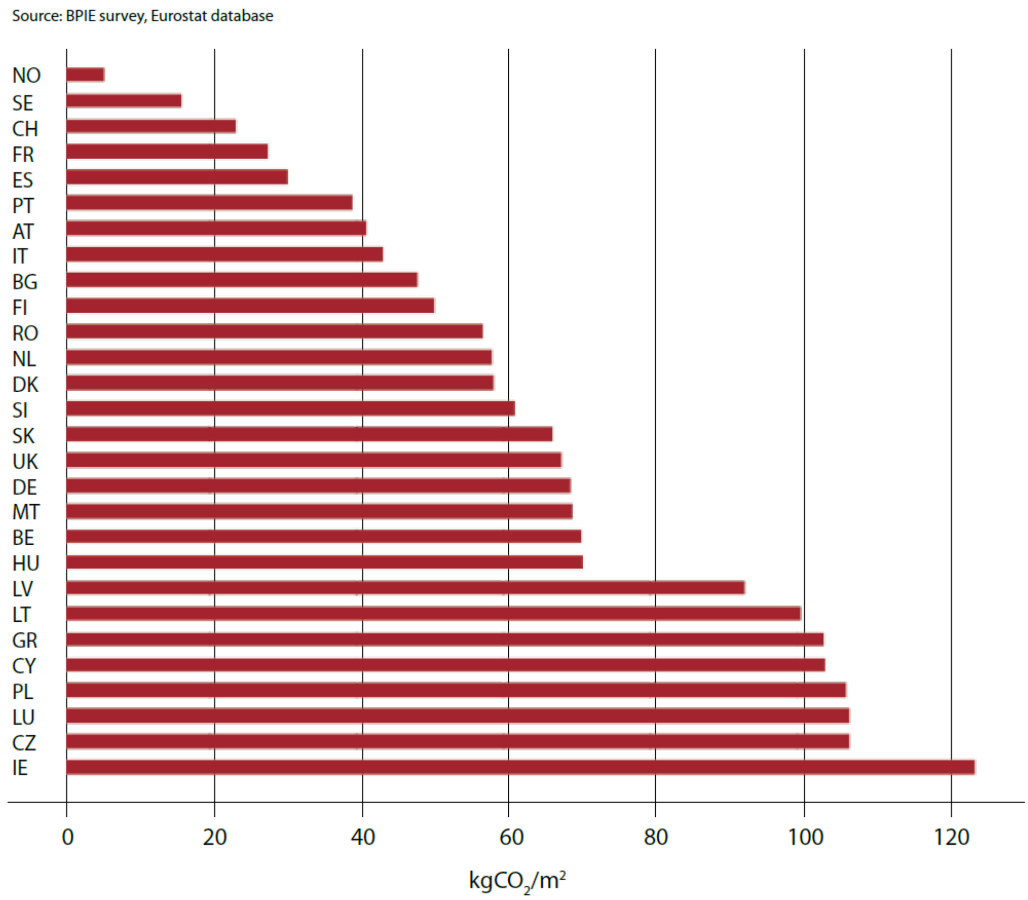


Figure 1.7. CO2 emission per useful floor area

1.5.4 Status of residential Building

Residential building in 2009 was responsible of the 68% of the total final energy use in buildings[9]. Energy in householders is mainly consumed by heating, cooling and hot water, cooking and appliances where the dominant energy end-use is space heating. The final consumption is shown in Figure 1.8 divided between all fuels and electricity. The strong correlation between heating degree days and fuel consumption emphasizes the link between climatic condition and energy use for heating as the yearly fluctuations in heating consumption are clearly dependent on climatic condition of a particular year.

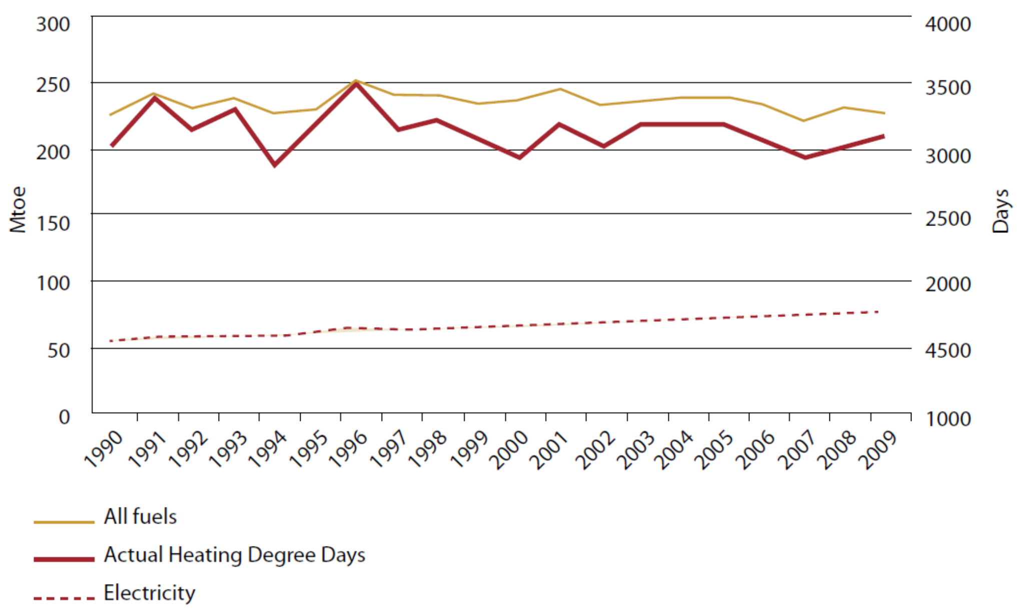


Figure 1.8. Historical final energy use in the residential sector in EU27, Norway and Switzerland

Figure 1.9 shows the end use of energy sources per region in 2009. Gas is the most common fuel which stands at 41%, 39% and 26% in North & West, South and Central & East regions, respectively. The highest use of coal in the residential sector is found in Central & Eastern Europe where the largest share is used in Poland. Oil use is highest in North & West Europe where Germany and France are the biggest consumers (inevitably due to the size of these countries). District heating is most common in Central & Eastern Europe and least in Southern countries while renewable energy sources (solar heat, biomass, geothermal, wastes) have a share of 21%, 12% and 9% in the total final consumption of Central & Eastern, South and North & West regions, respectively.

Space heating is the most energy intense end-use in EU homes and accounts for around 70% of our total final energy use. The percentage use for heating in Spain, Poland and France (a representative country per region), is indicated in Figure 1.10. This share is typically less in warmer climates (e.g. Spanish homes consumed 55% of the total final energy consumption in 2009) and also fluctuates from year to year. These examples shown signify the vast differences from country to country in terms of the corresponding energy mix. The energy mix for heating consumption is an indicator for the overall performance of a building .

[9] Data extracted from Eurostat: http://epp.eurostat.ec.europa.eu

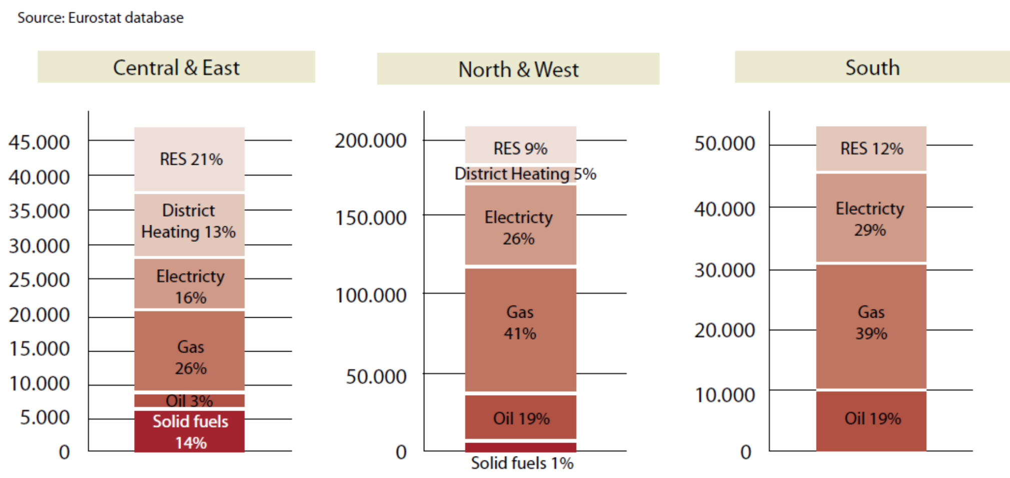


Figure 1.9. Final energy mix in residential buildings (thousand toe) by region, 2009

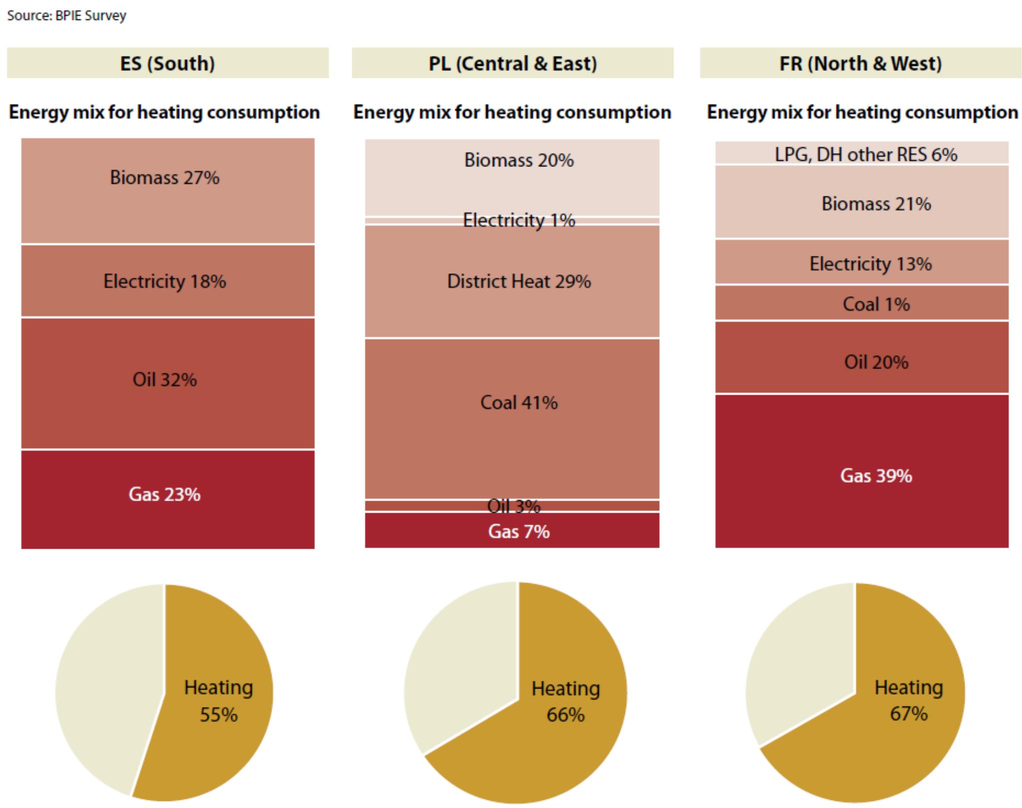


Figure 1.10. Share of heating consumption in terms of final energy use in residential buildings with corresponding energy mix

The performance of households depends on a number of factors such as the performance of the installed heating system and building envelope, climatic conditions, behavioural characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty meaning that not all buildings are used at maximum capacity). Despite different improvements in, for instance, heating systems, there is

still a large saving potential associated with residential buildings that has not been exploited. These technologies are easily implemented in new buildings, but the challenge is mostly linked to our existing stock which forms the vast majority of our buildings.
Sufficient thermal insulation of the building envelope is in fact essential for shielding the interior of the building from the exterior environment and minimising thermal transfer (heat losses or gains) through the envelope during the winter and summer periods. The lack of proper insulation in older buildings is clear in all countries due to the lack of insulation standards in those construction years.
The effect of the EPBD implementation can also be demonstrated especially in countries with no previous Prescriptive-based requirements for new buildings Member States have different prescriptive, element-based requirements associated with building energy codes such as maximum U values, minimum/maximum indoor temperatures, requirements for minimum ventilation rates and boiler and/or air conditioning plant efficiency. In addition to the lack of sufficient thermal insulation, gaps at connection points between different elements of a building envelope (e.g. window frame and surrounding wall) can lead to considerable energy wastage. This highlights the importance of appropriate air tightness levels in a building. A building with high air tightness levels (that is, high air leakage levels and high n50 values) typically suffers from high energy consumption levels while a building with very high air tightness levels can cause unhealthy conditions for its occupants, especially if there is inadequate ventilation. The latter is typically linked to poor indoor air quality and the so-called sick building syndrome. Establishing the appropriate level of air tightness in buildings is, therefore, a key aspect from the viewpoints of energy usage and comfortable occupant conditions. Poor detailing in past construction techniques means that older buildings encounter high leakage levels. However, even with today’s levels of air tightness levels, studies have shown that envelope leakage can increase the heating needs by 5 to 20 kWh/m²/a in a moderate climate (2500 to 3000 degree-days).

1.6 Criteria toward low energy bulidngs

Incorporating energy-related requirements during the design or retrofit phase of a building is a key driver for implementing energy efficiency measures which in turn highlights the role of building energy codes in reducing CO_2 emissions and reaching the energy saving potential of buildings. Several Member States introduced building code requirements (prescriptive criteria) associated with the thermal performance of buildings following the oil price increases in the 1970s while requirements in some Scandinavian countries have been in place since the mid-1940s.
The Energy Performance of Buildings Directive (EPBD, 2002/91/EC) was the first major attempt requiring all Member States to introduce a general framework for setting building energy code requirements based on a “whole building” approach (so called performance-based approach). Although subsidiary applies to implementation of the EPBD, Member States were required to introduce a methodology at the national or regional level to calculate the energy performance of buildings based upon this framework and apply minimum requirements on the energy performance of new buildings and large existing buildings subject to major renovation.
Following the EPBD in 2002, requirements have gradually started shifting from prescriptive to a performance-based approach which is regarded as a major change in the building code trends. Major changes are also expected through the application of the cost optimality concept in the energy performance requirements as introduced by the recast of the EPBD in 2010 (2010/31/EU). Member

States are required to set their national requirements in accordance with cost optimal levels by applying a harmonized calculation methodology (Article 5 and annex III of EPBD recast). This is currently being reviewed by the European Commission. The introduction of cost optimality in building regulations is likely to have a significant impact in many countries, with requirements being improved and further strengthened. Cost optimal levels should also gradually converge to nearly zero energy standards which would comprise a requirement for new buildings from 2020 onwards. Due to these foreseen changes, building codes are anticipated to be in a dynamic phase in the next decade.
Understanding building codes however requires specific technical expertise which makes monitoring and evaluating the progress of what is happening from the political level difficult. Given the environmental and climatic impacts of building codes, it is crucial to keep track of all the key transformations happening in the field of building energy codes in a simple, understandable way.
A summary of the key performance-based requirements and prescriptive criteria adopted by different countries is presented in Table 2B6. With the exception of a few countries, all countries have now embedded building regulations for both new and renovated buildings.

1.6.1 Performance based requirements for new buildings

For many countries the EPBD was the means of introducing new elements in their building codes prior to which there were no energy performance requirements concerning the building as a whole or specific elements. Nearly all countries have now adopted a national methodology which sets performance-based requirements for new buildings. For countries in which prescriptive requirements existed before 2002 (e.g. Czech Republic, Belgium, Estonia, Bulgaria, Hungary, Ireland, Poland), there was a shift towards a holistic-based (i.e. whole building) approach whereby existing single element requirements in many cases were tightened. Table 1.1 gives an overview of the current requirements in place. In some cases, the single element requirements are just supplementary demands to the energy performance requirements ensuring the efficiency of individual parts of a building is sufficient (e.g. Denmark). In others, they act as alternative methods where the two approaches exist in parallel (e.g. Norway, Spain, Poland, Switzerland); the first based on the performance of single elements and the second on the overall performance of a building. In Switzerland, for example, the holistic approach is used mainly for new buildings and the single element approach for shallow or deep renovations while in deep renovation cases, the holistic approach is sometimes chosen. In countries where the performance-based approach is the main form of requirement, most of the elements listed in the prescriptive criteria of Table 1.1 are already integral parts of the methodology, while additional elements such as RES (solar collectors, PV, heat pumps), summer comfort, indoor climate are embedded in the methodology.
While no country has directly and fully applied the CEN standards in their methodology procedures, many countries have adopted an approach which is broadly compatible with the CEN methodology. A variety of reasons were cited for not using the CEN standards, including difficulty of converting into practical procedures, timing and copyright issues. Most national procedures are applied as software programs and many countries have adopted a CEN based methodology (EN 15603: Energy Performance of Buildings) and/or are using the EN 13790 monthly calculation procedure, as the basis for the calculation "engine" for simple building. Others allow proprietary dynamic simulation (for more complex buildings), whilst others have developed their own national methods. The assessment of existing buildings (for building code or Certification purposes) is often based on a reduced data-set model.

Table 1.1. Summary of building energy code requirements and prescriptive criteria

Source: BPIE survey

	Building code requirements		Performance based requirements[1]		Prescriptive/element-based criteria in building codes					
	New build	Renovations	New build	Renovations	Thermal insulation	Air permeability	Ventilation requirements	Boiler/AC system efficiency	Lighting efficiency	Other requirements
AT	Y	Y	Y	Y	Y	Y	Y	Y	N	Summer comfort requirements
BE-Wl	Y	Y	Y	N	Y	N	Y	N	N	Overheating indicator should not exceed 17,500kh. T_{in} must be under 26oC for 90% of year in RE. K-values on global thermal insulation of entire building. Thermal bridges
BE-Br	Y	Y	Y	N	Y	N	Y	N	N	
BE-Fl	Y	Y	Y	N	Y	N	Y	N	N	
BG	Y	Y	Y	Y	Y	Y	N	Y	N	
CH	Y	Y	Y	Y	Y	N	N	Y	NRE	Thermal bridges, solar shading, max 80% of demand for heating & DHW covered by non-RES
CY	Y	Y	Y	Y	Y	N	N	N	N	Solar collectors in new RE
CZ	Y	Y	Y	Y	Y	Y	N	BO	N	T_{in} of 20oC in winter and 27oC summer
DE	Y	Y	Y	N	Y	Y	Y	Y	NRE	T_{in} (20-26oC), humidity, air change rate & air velocity requirements
DK	Y	Y	Y	N	Y	Y	Y	Y	NRE	Max T_{in} 26oC. Thermal bridges requirements
EE	Y	Y	Y	Y	Y	Y	Y	Y	NRE	RE & office temperature requirements
ES	Y	Y	Y	Y	Y	Y	Y	Y	NRE	Thermal comfort, T_{in} 21oC (winter), 26oC (summer), mandatory RES use (solar collectors/PVs)
FI	Y	P	Y	P[2]	Y	Y	Y	BO	Y	Max T_{in} applies (typically 25oC). Max CO_2 concentration in indoor air.
FR	Y	Y	Y	Y	Y	Y	Y	Y	NRE	Max T_{in} applies based on a number of factors
FR	Y	Y	Y	Y	Y	Y	Y	Y	NRE	Max T_{in} applies based on a number of factors
GR	Y	Y	Y	Y	Y	Y	Y	Y	N	
HU	Y	Y	Y	Y	Y	N	N	N	N	
IE	Y	Y	Y	N	Y	Y		Y		Thermal bridges
IT	Y	Y	Y	Y	Y	Y	Y	Y	N	
LT	Y	Y	Y	Y	Y	Y	Y	Y	N	
LV	Y	Y	N	N	Y	Y	Y	N	N	Orientation, window size, air temperature, air humidity & air velocity, specific heat losses of whole building & per m^2
MT	Y	N	N	N	Y	N	N	Y	NRE	Window size, glazing
NL	Y	Y	Y	N	Y	Y	Y		NRE	Daylight
NO	Y	Y	Y	Y	Y	Y	Y	Y	N	Window size, thermal bridges, ventilation fan power, heat recovery, summer/winter T_{in}
PL	Y	Y	Y	Y	Y	N	Y	Y	Y	Solar shading, window area
PT	Y	Y	Y	Y	Y	Y	NRE	Y	N	Max g-value,thermal bridge, solar collectors,cooling, DHW reqs apply
RO	Y	N	N	N	Y	N	N	N	N	Overall thermal coefficient g-value
SE	Y	Y	Y	Y	Y	Y	Y	Y	N	
SI	Y	Y	Y	Y[3]	Y	Y	Y	Y	N	Solar shading, max T_{in}
SK	Y	Y	Y	Y	Y	Y	Y	Y	N	Max T_{in}, humidity & air velocity apply.
UK	Y	Y	Y	Y	Y	Y	Y	Y	Y	

Table 1.2. Performance-based requirements for new buildings

Source: BPIE survey

	Single family houses	Apartment Blocks	Offices	Educational Buildings	Hospitals	Hotels & Restaurants	Sports facilities	Wholesale & retail trade
AT	H: 66 kWh/m^{2}a	H: 66 kh/m^{2}a	H:22.75 kWh/ m^{3}a	H:22.75 kWh/ m^{3}a C: 1kWh/m^{3}a	H:22.75 kWh/ m^{3}a C: 1kWh/m^{3}a	H:22.75 kWh/m^{3}a C: 1kWh/m^{3}a	H:22.75 kWh/ m^{3}a C: 1kWh/m^{3}a	H:22.75 kWh/m^{3}a C: 1kWh/m^{3}a
BE - Br	E70		E75	E75				E75 (services)
BE - Wl	E<100, Espec <170kWh/m^{2}a , Overheating <17500 kh/an	E<100	E<100	E<100				
BE - Fl	From 2012, E70 From 2014, E60	From 2012, E70 From 2014, E60	From 2012, E70 From 2014, E60	From 2012, E70 From 2014, E60				
BG	F:122-146 H&C: 82.5-102.5 kWh/m^{2}a	F: 90-146 H&C: 50.0-102.5 kWh/ m^{2}a	F: 80-132 H&C:40.0-82 kWh/m^{2}a	: 56-98 H&C: 40-82.0 kWh/m^{2}a	F: 180-242 H&C: 50-102.5 kWh/ m^{2}a	F: 176-230 H&C: 50-102.5 kWh/ m^{2}a	F: 90-134 H&C: 40-82 kWh/m^{2}a	F: 90-134 H&C: 40-82 kWh/m^{2}a
CH	Space heating demand (effective energy): 5 litre heating oil equivalent per m^2 (based on MuKEn 2008)							
	H: 54 kWh/m^{2}a	H: 42 kWh/ m^{2}a	H: 46 kWh/ m^{2}a	H: 43 kWh/ m^{2}a	H: 44 kWh/ m^{2}a	H: 58 kWh/ m^{2}a	H: 40 kWh/ m^{2}a	H: 36 kWh/ m^{2}a
CY	A or B category on the EPC scale							
CZ	F: 142 kWh/m^{2}a	F: 120 kWh/ m^{2}a	F: 179 kWh/ m^{2}a	F: 130 kWh/ m^{2}a	F: 310 kWh/ m^{2}a	F: 294 kWh/ m^{2}a	F: 145 kWh/ m^{2}a	F: 183 kWh/ m^{2}a
DE	New buildings must not exceed a defined primary energy demand for heating, hot water, ventilation, cooling and lighting installations (lighting installations only for commercial) based on of a reference building of the same geometry, net floor space, alignment and utilisation.							
DK	P: 52.5+1650/A kWh/m^{2}a	P: 52.5+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a	P: 71.3+1650/A kWh/m^{2}a
EE	P: 180 kWh/m^{2}a	P: 150 kWh/ m^{2}a	P: 220 kWh/ m^{2}a	P: 300 kWh/ m^{2}a	P: 400 kWh/ m^{2}a	P: 300 kWh/ m^{2}a	P: 300 kWh/ m^{2}a	P: 300 kWh/ m^{2}a
EL	The Primary energy requirement for new and renovated building in Greece is = 0.33 – 2.73 x Reference Building energy performance							
ES	The energy performance requirements is not expressed in units of kWh/m^{2}a							
FI	This is based on thermal transmittance (heat loss) measured in units of W/K. For a single family house, a typical value is 134 W/K							
FR-H1	P_{FF}: 130kWh/m^{2}a P_{ESH}: 250kWh/m^{2}a	P_{FF}: 130kWh/ m^{2}a P_{ESH}: 250kWh/ m^{2}a	n/a	n/a	n/a	n/a	n/a	n/a
FR -H2	P_{FF}: 110kWh/m^{2}a P_{ESH}: 190kWh/m^{2}a	P_{FF}: 110kWh/ m^{2}a P_{ESH}: 190kWh/ m^{2}a	n/a	n/a	n/a	n/a	n/a	n/a
FR -H3	P_{FF}: 80kWh/m^{2}a P_{ESH}: 130kWh/m^{2}a	P_{FF}: 80kWh/ m^{2}a P_{ESH}: 130kWh/ m^{2}a	n/a	n/a	n/a	n/a	n/a	n/a
HU	P: 110-230 kWh/ m^{2}a	P: 110-230 kWh/m^{2}a	P: 132-260 kWh/m^{2}a	P: 90-254 kWh/m^{2}a				
IE	MPEPC = 0.6 & MPCPC = 0.69	MPEPC = 0.6 & MPCPC = 0.69	MPEPC & MPCPC should not exceed 1	MPEPC & MPCPC should not exceed 1				
IT	Regulations for new buildings are based on a set limit for heating, DHW, cooling and lighting. Only Class A+ to C buildings comply with requirements for new buildings							

A detailed assessment of the energy performance requirements is provided in Table 1.2. It can be seen that many different approaches have been applied and no two countries have adopted the same approach. It is important not to attempt to compare the performance requirements set by Member States, given the variety of calculation methods used to measure compliance and major differences in definitions (e.g. definitions of primary and final energy, heated floor area, carbon conversion factors, regulated energy and total energy requirement etc.). The setting of building code requirements with

legally binding performance targets, is normally based on either an absolute value, generally expressed in kWh/m2a, or on a percentage improvement requirement based on a reference building of the same type, size, shape and orientation.
Most methodology procedures are applied as software programs. Software quality assurance accreditation is undertaken in only about half of the countries, a finding which has been drawn by the Concerted Action 2010 Report.
About 50% of Member States have already introduced changes to their methodology procedures to either to tighten requirements, achieve greater conformity with CEN standards, and include additional technologies and/or to correct weaknesses/gaps in earlier EPBD methodology procedures.
There is a growing interest in the harmonization of methodology procedures. This is likely to become an increasingly important issue in the context of the EPBD recast Article 2.2 and Article 9 requirements associated with nearly Zero Energy Buildings (nZEB) and cost optimality (EPBD recast Article 5) since the Commission will need to demonstrate that all Member States are delivering equivalent outcomes. A harmonized approach to setting and measuring nZEB targets and cost-optimality implies that a broadly equivalent methodology will be required.

Insulation
Limiting the thermal conductivity of major construction elements is the most common thermal performance requirement for buildings. These are based upon U value requirements (expressed in W/m2K) for the main building envelope construction elements. These U values are worst acceptable standards which as a stand-alone measure would not necessarily mean that a building meets the overall performance-based requirements in the respective country.
Country by country data on "maximum" U value requirements for roof, wall, floor, window and doors collected through the BPIE survey are shown in Table 1.3. These are presented against the relevant heating degree days per country or region. Given the diversity in climatic conditions, maximum U value requirements vary widely across different countries where Spain, France, Greece, Italy and Portugal have multiple maximum U values due to the considerable variation in climatic conditions within each country. In some countries, variations also apply for different types of buildings (e.g. Latvia) and type of heating (e.g. Sweden). A comparison between the collected data and the cost optimal U values published by EURIMA/Ecofys33 in 2007 (see Figure 2B7, blue line) confirm that Member State maximum U values are still higher than the cost-optimal requirements, suggesting that U value requirements in most Member States should be made more demanding. This was also one of the key findings of the IEA information paper on building codes34 where it was shown that existing U value requirements for building components did not reflect the economic optimum. From Table 1.3, it can be deducted that this is especially true for countries of mild or warm climates reflecting the equivalent magnitude of effort that is required in those countries. This comes as no surprise as countries in cold climatic zones have had longer traditions in thermal building regulations and therefore stricter requirements.

Air tightness/permeability and ventilation requirements
Most countries have introduced requirements to ensure minimum levels of ventilation within buildings. These are generally based upon metabolic rates and activity within the building. The requirements associated with ventilation relate principally to health, comfort and productivity; however they do have direct impact on energy requirements. The thermal performance of buildings is directly related to airtightness and the requirements for ventilation. Excessive ventilation as a consequence of poor construction detailing, can lead to considerable energy wastage and for this

reason a number of countries have introduced requirements to limit the air permeability of buildings. Air permeability is normally measured using a pressure test, typically at 50Pa to determine the air leakage rate. The requirement is typically expressed in $m^3/h.m^2$ (where m^2 is the external envelope area) or in the case of Denmark in l/s.m2 (where m2 is the floor area).

Other requirements

A number of Counntries have introduced minimum requirements for speific fan power. Given the increasing use of mechanical ventilation systems, the fan power requiremnt in low energy buildings is becoming an important issue. Additionally most countries have requirements associated with the minimum performance of boilers and air conditioning systems. Most building codes require minimum levels of daylight to be achieved within buildings, whilst ensuring that solar gains do not result in significant overheating and/or the requirement for air conditioning. Building requirements associated with limiting solar gains vary from simple approaches (e.g. limiting window areas on building aspects exposed to solar gains) through to requirements for complex modeling and simulation to demonstrate that effective measures have been adopted to provide solar protection. The Concerted Action report 1 recommended that much greater attention should be given to the issue of estimating the impact of summertime overheating in the methodology in order to reduce the rapid increase in demand for air conditioning.

In addition to specifying maximum U values, several countries have also set limits for maximum permissible thermal bridging. This is generally expressed in W/mK. Thermal bridges can significantly increase the building energy demand for heating and cooling and in nearly Zero Energy Buildings thermal bridging can account for a significant proportion of the total heat loss or gain. Thermal bridging is specific to the design and specification and can be complex and time consuming to calculate. For this reason, some countries allow a default thermal bridging value to be used, based upon a percentage (typically 15%) of the overall heat loss calculation. However, if a detailed thermal bridging calculation has been undertaken, which demonstrates that thermal bridges have been reduced or eliminated, this value can be used instead of the default.

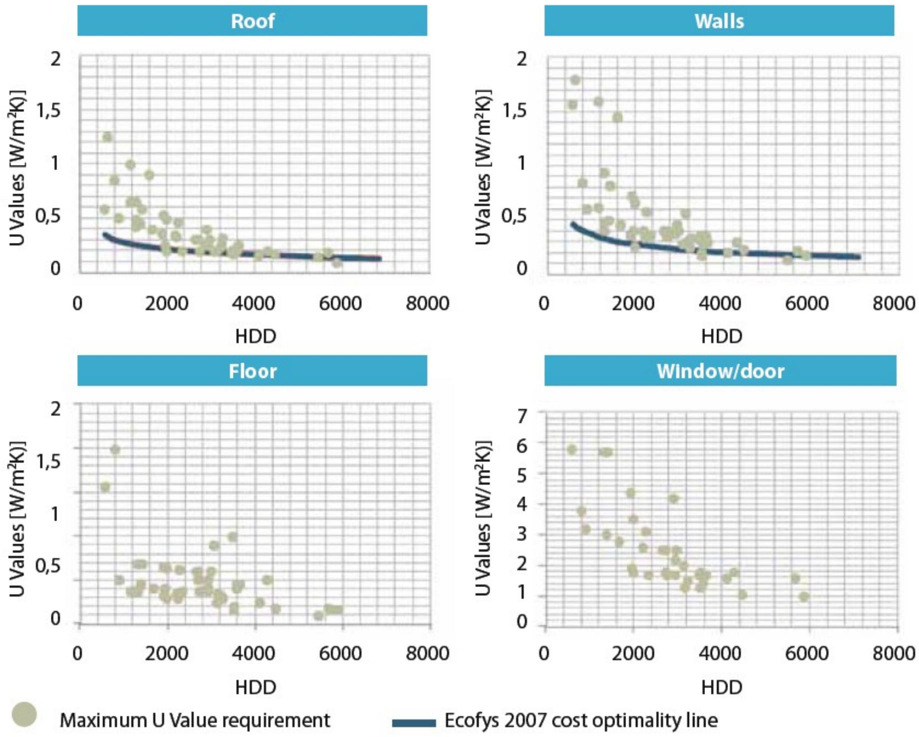
1.6.2 Building code requirements for existing buildings

Despite being an EPBD requirement, not all countries have reported specific mandatory building codes associated with improving the energy performance of existing buildings. It is important to recognise that EPBD (Article 5) only applies to buildings over 1000 m^2 and most Member States have introduced requirements for consequential improvements associated with buildings over 1000 m^2. It should be noted that these requirements may not be applied when they are not deemed to be "technically, functionally and economically feasible".

Table 1.4 provides a summary of different approaches adopted by a number of Member States when a building undergoes major renovation. Switzerland has adopted a very progressive approach to improving the performance of existing buildings, where the thermal performance of renovated buildings must not exceed 125% of the new building limit. A number of Member States have introduced minimum component performance standards when building elements (e.g. windows, doors etc.) or energy using plant (boilers, a/c equipment etc.) are being replaced. Good examples include countries which have a performance-based requirement as well as requirements for any component that is replaced or refurbished.

Table 1.3. Building envelope insulation requirements

Source : BPIE survey. Cost optimality line is based on the analysis undertaken by Ecofys in the study on U-Values for Better Energy Performance of Buildings, 2007



	MT	CY	PT	EL	ES	IT	LV (1)	FR	BG	BE	NL	IE	HU	SI
HDD(5)	560	782	1282	1663	1842	1907	1970	2483	2686	2872	2902	2906	2922	3053
Roof	0.59	0.85	0.9-1.25	0.35-0.5	0.45-0.65	0.32-0.65	0.2κ-0.35κ	0.2-0.25	0.3	0.3	0.4	0.25	0.25	0.2
Walls	1.57	0.85	1.45-1.8	0.4-0.6	0.57-0.94	0.33-0.62	0.25κ-0.5κ	0.36-0.40	0.35	0.4	0.4	0.37	0.45	0.28
Floor	1.57	2		0.45-0.5	0.62-0.69	0.29-0.38	0.2κ-0.35κ	0.37-0.40	0.5	0.6	0.4	0.37	0.45	0.9
Window/ Door	5.8	3.8		2.6-3.2	3.1-5.7	1.3-3.7	1.8κ-2.4κ	1.7-1.9	1.8	2.5	4.2	2.2	1.6	1.1 -1.6

	UK(3)	RO	DE	SK	CH(2)	DK	CZ	AT	PL	LT	EE	SE(4)	NO	FI
HDD	3115	3129	3239	3453	3482	3503	3571	3573	3616	4094	4444	5444	5646	5850
Roof	0.2	0.2	0.24	0.19	0.17 or 0.2	0.2	0.24	0.2	0.25	0.16	0.15-0.2		0.18	0.09
Walls	0.3	0.56	0.24	0.32	0.17 or 0.2	0.3	0.3	0.35	0.3	0.2	0.2-0.25		0.22	0.17
Floor	0.25	0.35	0.3		0.17 or 0.2	0.2	0.45	0.4	0.45	0.25	0.15-0.2	0.4-0.6	0.18	0.16
Window/ Door	2	1.3		1.7	1.3	1.8	1.7	1.4	1.7	1.6	0.7-1.4		1.6	1.0

NOTES

(1) Depending on type of building (residential, public, industrial etc.) where κ is a temperature factor, κ = 19/(Tin-Tout), Tin and Tout denote indoor and outdoor temperatures, respectively.
(2) Depending on evidence of thermal bridges
(3) For England & Wales
(4) Depending on type of building (residential and non residential) & type of heating (electric and non electric). These represent overall U values
(5) Mean HDD values for period 1980-2004 based on Eurostat data

LEGEND

HDD: Heating degree days.

Table 1.4. Building code requirements for existing buildings

Source: BPIE survey

AT	Specific maximum heating energy demand targets for major renovation of residential and non-residential buildings. Values for renovated buildings are around 25-38% higher than new build requirements. Heat recovery must be added to ventilation systems when renewed. Maximum permitted U values for different elements in case of single measure or major renovations. Prescriptive requirements to limit summer over-heating.
BE	Maximum U values and ventilation requirements apply depending on the region.
BG	Regulations requiring performance-based standards of existing housing and other buildings after renovation. Requirements for new and renovated buildings are the same.
CH	Renovated buildings are required to use no more than 125% of the space heating demand of an equivalent new building. A single element approach may also be applicable for renovations.
CY	Minimum energy performance requirements (class A or B) for buildings over 1,000 m^2 undergoing major renovation.
CZ	Performance-based requirements when a building over 1,000 m^2 is renovated. Requirements for new and renovated buildings are the same.
DE	Conditional requirements apply in the case of renovation of components whereby requirements extend exclusively to those parts of the building surface and parts of the installation that are the subject of the measures. Alternatively, a holistic assessment can also be made where values for renovated buildings should not exceed new build requirements by more than 40%.
DK	Component level requirements when existing buildings are refurbished for all improvements or extensions regardless of building size.
EE	Performance-based requirements for all building types when buildings are major renovated. Values for renovated buildings are around 25-38% higher than new build requirements.
ES	Existing buildings over 1,000 m^2 must comply with the same minimum performance requirements as new buildings if more than 25% of the envelope is renovated.
FI	Reference transmittance/heat loss (in W/K) requirements apply. New energy performance regulations will be launched in 2012.
FR	Performance-based requirements for buildings undergoing renovation apply for residential buildings and values depend on the climate and type of heating (fossil fuel/electricity). Requirements for components also apply during building renovation. New renovation requirements for all buildings from 2013.
HU	Performance-based requirements (in terms of primary energy) apply for residential buildings, offices and educational buildings. Requirements for new and renovated buildings are the same.
LT	Buildings over 1,000 m^2 undergoing major renovation must achieve the energy performance standard of a Class D building where D corresponds to 110 kWh/m^2a for buildings > 3,000 m^2; 130 kWh/m^2a for buildings from 501 to 3,000 m^2; 145 kWh/m^2a for buildings up to 500 m^2.
LV	Requirements on different elements are applicable.
MT	U value requirements for existing renovated buildings.
NL	The Energy Performance Standard (EPN) sets requirements for the energy performance of major renovations of existing buildings (expressed as an energy performance coefficient).
NO	Building regulation requirements only apply when the purpose or use of the building is changed at renovation or if considered so extensive as to be equivalent to a new building.
PT	Special requirements for buildings over 1,000 m^2 and over a specified threshold energy cost. A mandatory energy efficiency plan must be prepared and all energy efficiency improvement measures with a payback of less than 8 years must (by law) be implemented. The threshold is based upon 40% of the worst performing buildings by typology.
SI	Minimum requirements apply to major renovations (i.e. if at least 25 % of the envelope is renovated). The requirements apply to buildings of all size (NB the 1,000 m^2 limit is not used). Min. requirements apply for the renovation of heating systems.
SK	Requirements for improving the thermal performance of apartment by at least 20% when being renovated.
UK	Specific requirements when replacing "controlled elements" such as windows, boilers and thermal elements in residential buildings. Consequential improvement requirements for buildings over 1,000 m^2 undergoing major renovation in so far as they are "technically, functionally and economically feasible".

1.7 References

[1] [Principles For Nearly Zero-energy Buildings. Ecofys Germany GmbH: Thomas Boermans, Andreas Hermelink, Sven Schimschar, Jan Grozinger, Markus Offermann.Danish Building Research Institute (SBi): Kirsten Engelund Thomsen, Jorgen Rose, Soren O. Aggerholm. Buildings Performance Institute

[2] Directive 2010/31/EU of The European Parliament And Of The Council of 19 May 2010 on the energy performance of buildings (recast) Europe (BPIE), 2011.

[3] Low Energy Buildings In Europe: Current State Of Play, Definitions And Best Practice, 2009 Bruxelles. http://ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf

[4] Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012. Supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

[5] EN 15603:2008 “Energy performance of buildings - Overall energy use and definition of energy ratings”.

[6] CEN/TR 15615. “Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) - Umbrella Document”

[7] EN 15251:2007. “Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics”.

[8] Europe’s Buildings Under The Microscope. B.Atanasiu, C.Despret, M. Economidou, J. Maio, I. Nolte, O. Rapf. Buildings Performance Institute Europe (BPIE), 2011

[9] Paul Hawken - The HOK Guidebook to Sustainable Design

CHAPTER

2

RETROFIT OF A SINGLE DWELLING HOUSE

Abstract
This chapter presents an analysis carried out to assess the effectiveness in terms of reduction of the primary energy demand of a retrofit according to the building envelope and the HVAC system in a single dwelling house. The analysis has been realized by the means of dynamic simulation ran with the commercial transient code TRNSYS. A model of the building and of the thermal system has been implement according to the situation before and after the retrofit, and several redevelopment actions have been evaluated in order to achieve the maximum energy saving. The retrofit of the building envelope has been investigate according to a proper insulation of the external surfaces and the replacement of the obsolete windows. Regarding the system, the actions taking into account concern both the heat generation devices, including condensing gas boiler, heat pump, solar collectors in substitution of the conventional gas boiler, both the heat emission system which has been evaluate according to cast iron radiators, fan coils and radiant floor panels.
The analysis provides a noticeable result, according to energy saving, related to the retrofit of existing building and the installation of the integrated multi-energy system, in which several generation devices are combine in order to operate in their most suitable conditions.

2.1 Introduction

The European Commission by the means of the Energy Performance of Building Directive (EPDB)[1] recall all the States members to the agreement of the Kyoto Protocol. The Eu-15 engaged in an 8% of reduction of the greenhouse gas emission by the 2012 respect to the value recorded on the 1990. The actual state shows a reduction of the 0.09%. The situation according to Italy is even worse, despite a prevision of 6.5 % of reduction of carbon gas, the present value is set to an increase of 13% respect to the 1990.
In order to maintain the taken commitments a road map has to be traced to achieve a substantial reduction of the energy demand and the increase of Energy efficiency in buildings. What is sure is that the retrofit of the existent building stock is a crucial step of the process.
In addition to the environmental benefit, social and economical reasons promote the retrofit of buildings: the increase of the Energy efficiency and the development of renewable resources are important means toward the technological and economical development and the creation of new employment.
The activity described in this chapter focus on the retrofit of a single dwelling house. Several actions, concerned both the envelope and the HVAC systems, have been analyzed in order to achieve an

Energy reconditioning of the building. By the means of dynamic simulations the reduction of the heating Energy demand has been evaluated to asset the effectiveness of the redevelopment.
The analysis has been carried out on the basis of the original state of the building. The case study has been modeled trough the numerical code and several actions have been accounted for the retrofit. Each analysis has been evaluate the thermal energy demand according to heating and DHW generation, and the results have been compared to determine the solutions that allows the minimum primary energy demand.
The actions affected the envelope are the insulation of the opaque structures (walls, roofs, and basement) by the means of an external coating with insulation, and the replacement of the windows, with ones with better thermal performance. Changing on the HVAC systems have been evaluated as well, like as: the replacement of the gas conventional boiler with a condensing one, the installation of a thermal solar system, the installation of a air-water heat pump, the placement of a controlled mechanical ventilation equipment (CMV), the substitution of the old radiators devices with fan coil and radiant floor system. The several combinations of actions take into account in the study are presented in
Table 2.1 Actions on the Envelope and HVAC system

ACTIONS	0	A1	A2	B1	B2	B3	B4
Not insulated building	■	■	■				
Insulated building				■	■	■	■
Conventional gas boiler	■						
Gas condensing boiler		■	■	■	■	■	■
Solar thermal collectors				■	■	■	■
Air-water heat pump						■	■
MCV				■	■	■	■
Radiators, high temperature	■						
Radiators, low temperature		■		■			
Fan coils			■				■
Radiant floor system					■	■	

Table 2.1 Actions on the Envelope and HVAC system

2.2 References to Italian Regulation

The analysis was conducted on the basis of the Italian regulation. The property of the building envelope and of the plant, as well as the management of the HVAC system, are regulated in Italy both inn heating and in cooling conditions.
The .D.P.R. n. 412/93 (Decree of the President of the Republic) [2] contains the national regulation according to design, installation, functioning and maintenance of the HVAC of buildings, in order to reduce the annual Energy demands.
The management of the heating systems are ruled by the D.P.R. n. 74/13[3], according to the maximum allowed indoor temperature, the extension of the heating season, and the maximum number of hours of functioning per day. (Table 2.2). On the basis of the Degree Day parameter (DD) the Italian territory has been divided in six climatic zones (Figure 2.1) with different values for the listed items.

Table 2.2. Climatic zone and parameters for heating conditions according to Italian regulation

Climatic Zone	Degree Day	Operating period	Daily hours of operation
A	DD ≤ 600	01/12 – 15/03	6 hours per day
B	600 < DD ≤ 900	01/12 – 31/03	8 hours per day
C	900 < DD ≤ 1400	15/11 – 31/03	10 hours per day
D	1400 < DD ≤ 2100	01/11 – 15/04	12 hours per day
E	2100 < DD ≤ 3000	15/10 – 15/04	14 hours per day
F	DD > 3000	No limitation	No limitation

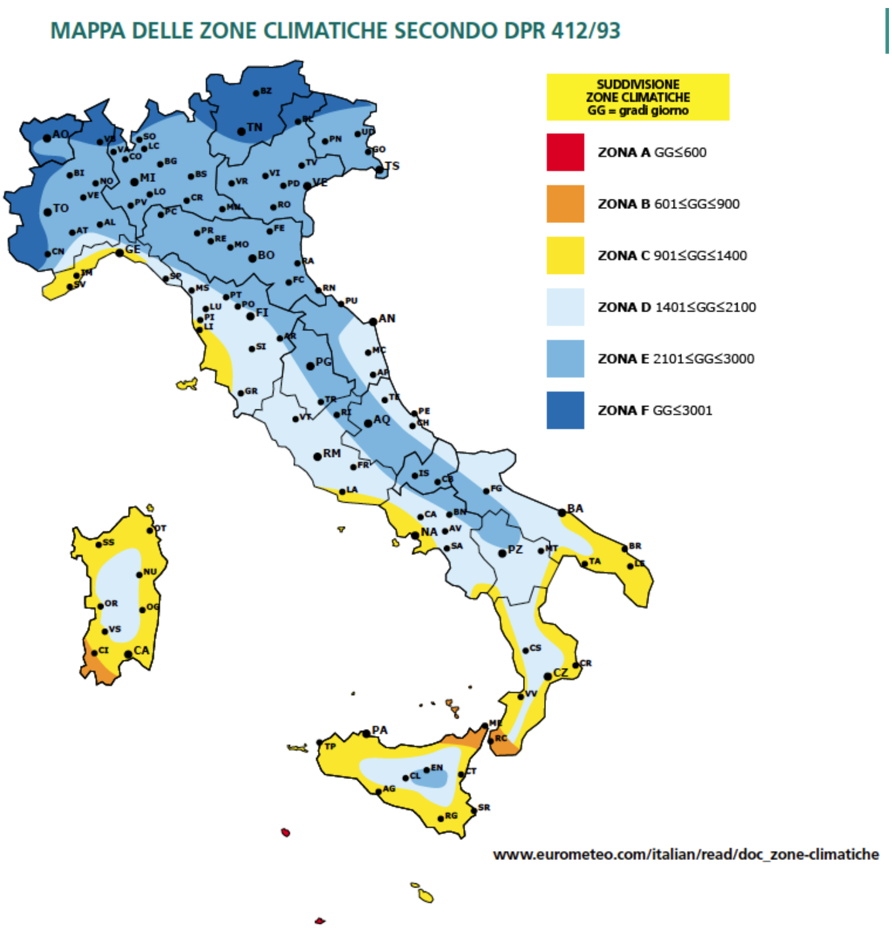


Figure 2.1. Climatic zone map of Italian territory

On the basis of the climatic zones the property for the thermal behavior of the building envelope are stated, maximum U-value threshold are given for walls and windows. as well as the heating seasonal index of energetic performance of the building.
The Table 2.3and the Table 2.4 present the maximum threshold value for the yearly heating energy demand for dwelling in the climatic zone E and the maximum allowed U-value for the envelope for all type of buildings.
In order to evaluate the total energy demand of a building, the heating and the DHW generation Energy demand have to been increased according to the overall efficiency of the system. The overall efficiency of the energy system is defined as the factor of four coefficient of performance related to

the heat emission devices, the distribution system, the regulation and management components and the generation system. The procedure for the calculation of these efficiencies is discussed in the regulation UNI/TS 11300-2 [4].

Table 2.3 Threshold value for the yearly heating energy demand for dwelling in the climatic zone E

dispersing surface/heated volume ratio	Climatic Zone									
	A	B		C		D		E		F
	up to 600 DD	from 601 DD	up to 900 DD	from 901 DD	up to 1400 DD	from 1401 DD	up to 2100 DD	from 2101 DD	up to 3000 DD	over 3000 DD
≤ 0.2	7.7	7.7	11.5	11.5	19.2	19.2	27.5	27.5	37.9	37.9
≥ 0.9	32.4	32.4	43.2	43.2	61.2	61.2	71.3	71.3	94.0	94.0
Threshold values, expressed as kWh/m²year, are valid from the 1st January 2010										

Table 2.4. maximum allowed U-value for the envelope for all type of buildings

Climatic Zone	Vertical structures	Orizzontal and slope structures		Windows and related structures
		Roofs	Floors	
A	0.54	0.32	0.60	3.7
B	0.41	0.32	0.46	2.4
C	0.34	0.32	0.40	2.1
D	0.29	0.26	0.34	2.0
E	0.27	0.24	0.30	1.8
F	0.26	0.23	0.28	1.6
Threshold values, expressed as W/m²K, are valid from the 1st January 2010				

Heat emission devices

The evaluation of the heat emission efficiency is highly influenced by the geometrical property of the analyzed indoor volume, particularly by its height. The Table 2.5 of the UN/TS 1100-2 provides reference values for floors not higher than 4 m.

Table 2.5 Heat emission efficiency

Heat emission devices	average yearly heating load [W/m³]		
	<4	4-10	>10
		η_e	
Radiators on external insulated wall	0.95	0.94	0.92
Radiators on internal wall	0.96	0.95	0.92
Fan coils , operating temperature = 45°C	0.96	0.95	0.94
Convector heater	0.94	0.93	0.92
Hot air vent	0.94	0.92	0.90
Insulated radiant floor system	0.99	0.98	0.97
Not insulated radiant fool system	0.98	0.96	0.94
Radiant ceiling system	0.97	0.95	0.93
Radiant wall system	0.97	0.95	0.93

Management system

The efficiency of the HVAC management system is provided, by the Table 2.6, for several types of controllers combined with the different possible emission devices.

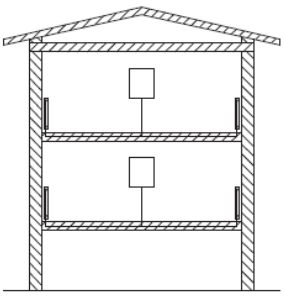
Table 2.6. Management system efficiency

Type of controller	**Description**	**System with low thermal inertia**	**System with high thermal inertia**	
		radiators, thermal convectors, fan coils, hot air heat strips	Drowned radiant system thermally uncoupled	Drowned radiant system thermally coupled
Climatic controll (external probe)		$1 - (0.6\ \eta_u\ \gamma)$	$0.98 - (0.6\ \eta_u\ \gamma)$	$0.94 - (0.6\ \eta_u\ \gamma)$
Only indoor with controller	On Off	0.94	0.92	0.88
	PI o PID	0.99	0.97	0.93
	P band prop 0.5°C	0.98	0.96	0.92
	P band prop 1°C	0.97	0.95	0.91
	P band prop 2°C	0.95	0.93	0.89
Climatic + indoor with controller	On Off	0.97	0.95	0.93
	PI o PID	0.995	0.99	0.97
	P band prop 0.5°C	0.99	0.98	0.96
	P band prop 1°C	0.98	0.97	0.95
	P band prop 2°C	0.97	0.96	0.94
Indoor zone + controller	On Off	0.93	0.91	0.87
	PI o PID	0.995	0.99	0.97
	P band prop 0.5°C	0.99	0.98	0.96
	P band prop 1°C	0.98	0.97	0.95
	P band prop 2°C	0.94	0.93	0.88
Climatic + Indoor zone with controller	On Off	0.96	0.94	0.92
	PI o PID	0.995	0.98	0.96
	P band prop 0.5°C	0.98	0.97	0.95
	P band prop 1°C	0.97	0.96	0.94
	P band prop 2°C	0.96	0.95	0.93
Note	γ	gains/losses ratio		
	η_u	utilization factor of gains		

Delivery system

The evaluation of the delivery thermal losses could be realized according to the Table 2.7 , derived by the regulation UNI/TS 11300-2.

Table 2.7. Heat delivery system efficiency for independent systems.

INDEPENDENT SYSTEMS				
	Insulation rate of the delivery system			
	Good Building time after 1993	Discreet Building time 1993-1977	Average Building time 1976-1961	Insuficient Building time before 1961
	0.990	0.980	0.969	0.958

Heat generation system

The losses due to the generation of the heat for the air conditioning and the DHW generation depend not only from the characteristics of the heat generator device itself but they are also highly affected by the way it is linked to the rest of the system. Particularly the size of the generators respect to the heat demand, the methods of installation, the management in operating condition and the set-point temperature of the delivered water concur to determine the heat generation efficiency.

The seasonal generation efficiency differs then from the efficiency evaluated in testing conditions. The regulation provide a procedure to esteem the correct value for the analyzed system, on the basis of reference values evaluated for the most common heat generators devices. The procedure is presented in the Table 23b of the UNI/TS 11300-2 and in the relative discussion.

2.3 The Case Study

The investigated building consists in a single dwelling house, composed by three floors, located in the Treviso area, in the North East of Italy. The degree days calculated for the building location are 2505 so it is in the E climatic zone. The weather data of the main Italian city are collected in the national regulation UNI 11349 [5]. For the town of Treviso, the norm provide an design external temperature of -5°C, an average external temperature of 13,4 °C and a design indoor temperature equal to 20°C.

2.3.1 The Building Envelope

It has been said that the case study is a three storey building, composed by a ground floor, a first floor and a garret. The geometrical characterization of each floor is following presented.

The ground floor has a global area of 96.14 m^2, of which 60.36 m^2 represent the heated zone. In Figure 2.2 a map of the floor is presented. The Table 2.8 displays the area and the volume of each room and the Table 2.9 shows the geometrical dimensions of walls and windows.

Figure 2.2. Map of the ground floor

Table 2.8. Description of the ground floor

Room	Area [m^2]	Volume [m^3]
DINING ROOM	37.55	105.14
BATHROOM	5.20	14.04
CLOSET	6.94	18.74
CELLAR	6.04	16.31
STRAIR WELL	17.61	47.55
HALLWAY	5.13	13.85
GARAGE	11.40	30.78
BOILER ROOM	6.27	19.63

Table 2.9. External structures description of the ground floor

Orientation	Walls area [m^2]	Windows area [m^2]	Total area [m^2]
NORTH	31.47	-	31.47
SOUTH	15.15	2.88	18.03
	12.36	1.08	13.44
EAST	26.64	7.80	34.44
WEST	14.28	3.08	17.36
	13.72	3.36	17.08

The first floor has a global area of 115.33 m^2 and a volume equal to 311.19 m^3, and it is complete heated. The Table 2.10 displays the area and the volume of each room and the Table 2. 11 shows the geometrical dimensions of walls and windows.

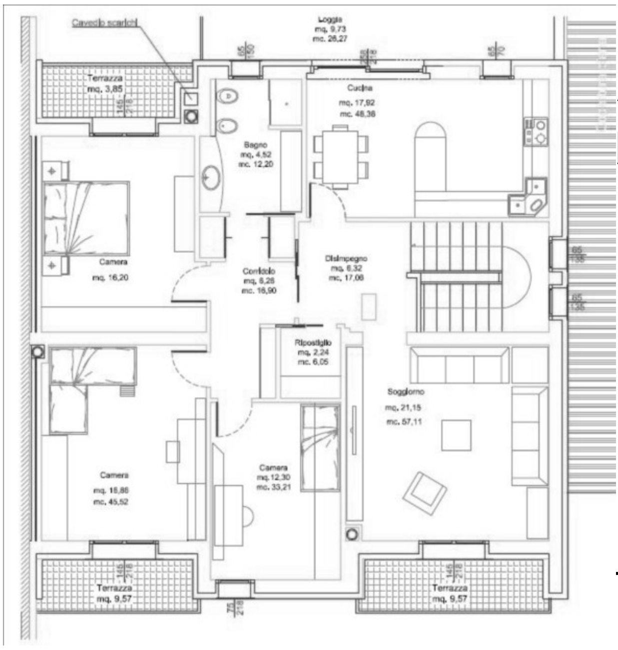


Figure 2.3. Map of the first floor

Table 2.10. Description of the first floor

Room	Area [m^2]	Volume [m^3]
BEDROOM NE	16.20	43.74
BEDROOM NW	16.86	45.52
BEDROOM W	12.30	33.21
LIVING ROOM	21.15	57.11
HALLWAY	5.13	13.85
KITCHEN	17.92	48.38
ACCESS ROOM	14.40	38.88
CLOSET	2.24	6.05
BATHROOM	6.84	18.47

Table 2. 11. External structures description of the first floor

Orientation	Walls area [m^2]	Windows area [m^2]	Total area [m^2]
NORTH	31.70	-	31.7
SOUTH	29.46	2.24	31.7
EAST	27.12	7.57	34.69
WEST	24.67	10.02	34.69

The garret is an not heated unique room with a surface of 121.22 m^2 and a volume equal to 143.17 m^3. The area of the roof is equal to 174.24 m^2. The roof has two 15° slope surfaces disposed with an East-West orientation (Figure 2.4 and Table 2. 12).

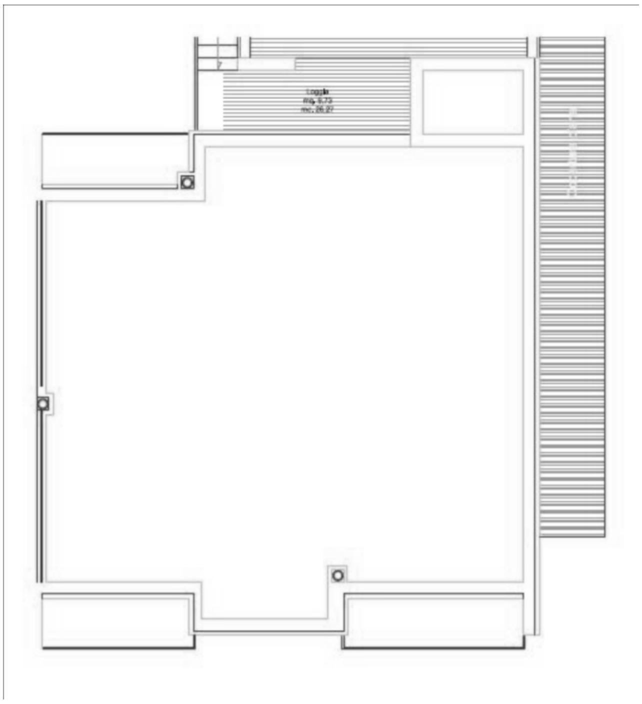


Figure 2.4. Map of the garret

Table 2. 12. External structures description of the garret

Orientation	Walls area [m^2]	Windows area [m^2]	Total area [m^2]
EAST	87.12	-	87.12
WEST	87.12	-	87.12

Tables from Table 2.13 to Table 2.20 present the thermal property of the envelope. Several physical characteristics of the structures are presented: density of the materials (D, [kg/m^3]), thickness of the layers (s, [cm]), thermal conductivity test and average value (λ, $\lambda_{m,}$ [W/m^2K]), thermal resistance (r, [m^2K /W]) and the thermal capacity of the material (CT, [kJ/kgK]).

Table 2.13. External roof physical and thermal properties

EXTERNAL ROOF							
Description	**D**	**s**	**λ**	**m**	**λ_m**	**r**	**CT**
Indoor air							
Liminal inner layer						0.100	
Tavel. roof structure 2.1.02i 60	617	6			0.428	0.140	0.92
Standard concrete	2200	4	1.28	0	1.28	0.031	0.88
Bitumen	1200	0.4	0.17	0	0.17	0.024	0.92
Liminal outer layer						0.100	
TOTAL		10.4				0.365	
U-value [W/(m^2K)]				2.74			

Table 2.14. External wall physical and thermal properties

EXTERNAL WALL							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Lime cement sand mortar	1800	2.5	0.9	0	0.9	0.028	0.91
Perforated brick 1.1.04 (b) 250	1188	25			0.533	0.469	0.92
Lime mortar or lime concrete	1800	2.5	0.9	0	0.9	0.028	0.91
Cement smoother	1650	0.5	0.51	0	0.51	0.010	0.86
Plaster in paste	1800	0.3	0.7	0	0.7	0.004	1
Liminal outer layer						0.040	
TOTAL		30.8				0.709	
U-value [W/(m^{2}K)]	1.411						

Table 2.15. Internal floor physical and thermal properties

INTER-FLOOR							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.5	1	0	1	0.015	0.84
concrete with polystyrene	500	10	0.15	0	0.15	0.667	0.92
Lime mortar or lime concrete	1800	2	0.9	0	0.9	0.022	0.91
Block attic 2.1.031/1	950	18			0.599	0.300	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Liminal outer layer						0.170	
TOTAL		32.5				1.185	
U-value [W/(m^{2}K)]	0.844						

Table 2.16. Structural partition physical and thermal properties

STRUCTURAL PARTITION							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Plasterboard	750	2.5	0.6	0	0.6	0.042	0.84
Perforated brick 1.1.04 (b) 250	1188	25			0.533	0.469	0.92
Lime mortar or lime concrete	1800	2.5	0.9	0	0.9	0.028	0.91
Liminal outer layer						0.130	
TOTAL		30				0.799	
U-value [W/(m^{2}K)]	1.252						

Table 2.17. Internal wall physical and thermal properties

INTERNAL WALL 10							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Hollow brick 1.1 19 80	775	8			0.4	0.200	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Liminal outer layer						0.130	
TOTAL		10				0.482	
U-value [W/(m^{2}K)]	2.074						

Table 2.18. Outdoor floor physical and thermal properties

OUTDOOR FLOOR							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.5	1	0	1	0.015	0.84
Concrete with polystyrene	500	8	0.15	0	0.15	0.533	0.92
Lime mortar or lime concrete	1800	2	0.9	0	0.9	0.022	0.91
Block slab 2.1.031 / 1	950	18			0.599	0.300	0.92
Cement smoother	1650	0.5	0.51	0	0.51	0.010	0.86
Plaster in paste	1800	0.3	0.7	0	0.7	0.004	1
Liminal outer layer						0.040	
TOTAL		30.3				1.055	
U-value [W/(m^2K)]	0.948						

Table 2.19. Basement physical and thermal properties

BASEMENT							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.3	1	0	1	0.013	0.84
Concrete with polystyrene	500	10	0.15	0	0.15	0.667	0.92
Extruded Polystyrene Foam	50	5	0.032	0	0.032	1.562	1.25
Ordinary concrete	2200	5	1.28	0	1.28	0.039	0.88
Pebbles and crushed stones	1500	8.6	0.7	0	0.7	0.123	0.84
Liminal outer layer						0.040	
TOTAL		29.9				2.577	
U-value [W/(m^2K)]	0.388						

Table 2.20. Floor attic physical and thermal properties

FLOOR ATTIC							
Description	D	S	λ	M	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Sheath vapor barrier	133	0.1			0.4	0.002	0.84
Ordinary concrete	2200	2	1.28	0	1.28	0.016	0.88
Block slab 2.1.031 / 1	950	18			0.599	0.300	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Liminal outer layer						0.170	
TOTAL		21.1				0.500	
U-value [W/(m^2K)]	2.001						

2.3.2 Internal Gains

The already recalled regulation UNI/TS 11300-1[6] provides the procedure for the evaluation the overall energy demand of a building. The amount of the internal gains could be determine on the basis of the utilization of the building. The section 8 of the regulation suggests a conventional value of about 6 W/m^2 in order to asses the amount of internal gains of a residential building. The internal gains of a dwelling are typically due to the presence of people, to appliances and personal computers, electrical devices, lighting systems, hot water supply and to cooking. In the analysis carried out the scheduling presented in Table 2.21 has been considered for the people occupancy.

Table 2.21. Occupancy data used to count the presence of people inside the analyzed building.

OCCUPANCY	Day	Night	Day & Night
0:00-7:00	0	1	1
7:00-8:00	0.5	0.5	1
8:00-9:00	0.5	0	0.5
9:00-16:00	0.12	0	0.12
16:00-19:00	0.5	0	0.5
19:00-20:00	1	0	1
20:00-22:00	0.5	0.5	1
22:00-24:00	0	1	1

The given profile must be multiplied by the number of inhabitants and by the value of the sensible and the latent heat flux emitted from each person indicated in the European regulation UNI EN ISO 7730 [7] related to the comfort of the indoor environment. The Table 2.22 provides the scheduling for the lighting system.

Table 2.22. Scheduling used to count the inside the analyzed building

LIGHTING	Day	Night	Day & Night
0:00-7:00	0	0	0
7:00-8:00	0.5	0.5	1
8:00-9:00	1	0	1
9:00-16:00	0	0	0
16:00-19:00	0.5	0	0.5
19:00-20:00	0.5	0	1
20:00-22:00	0.5	0.5	1
22:00-24:00	0	0	0

The lighting profile must be multiplied by the thermal flux emitted by the light source expressed in W/m^2, and for the area of the involved room. In the case study a mean flow equal to 5 W/m^2 has been consider, 40% of which came from fluorescence lamps.
Concerning to the demands of domestic hot water the water profile has been modeled on the basis of the statistical profile of 300 l/day, provided in the Annex 42 [8] edit by the International Energy Agency. The annex contains the load profiles for several domestic hot water demand calculated on a statistical basis according with data recorded around Europe.

2.3.3 Description of the HVAC System

The HVAC system analyzed in the present study is sown in Figure 2.5. It is an integrated multi-energy system, that means that several heat generators are combine in order to satisfy the Energy demand for heating and DHW generation. Only the operation in winter conditions was studied.

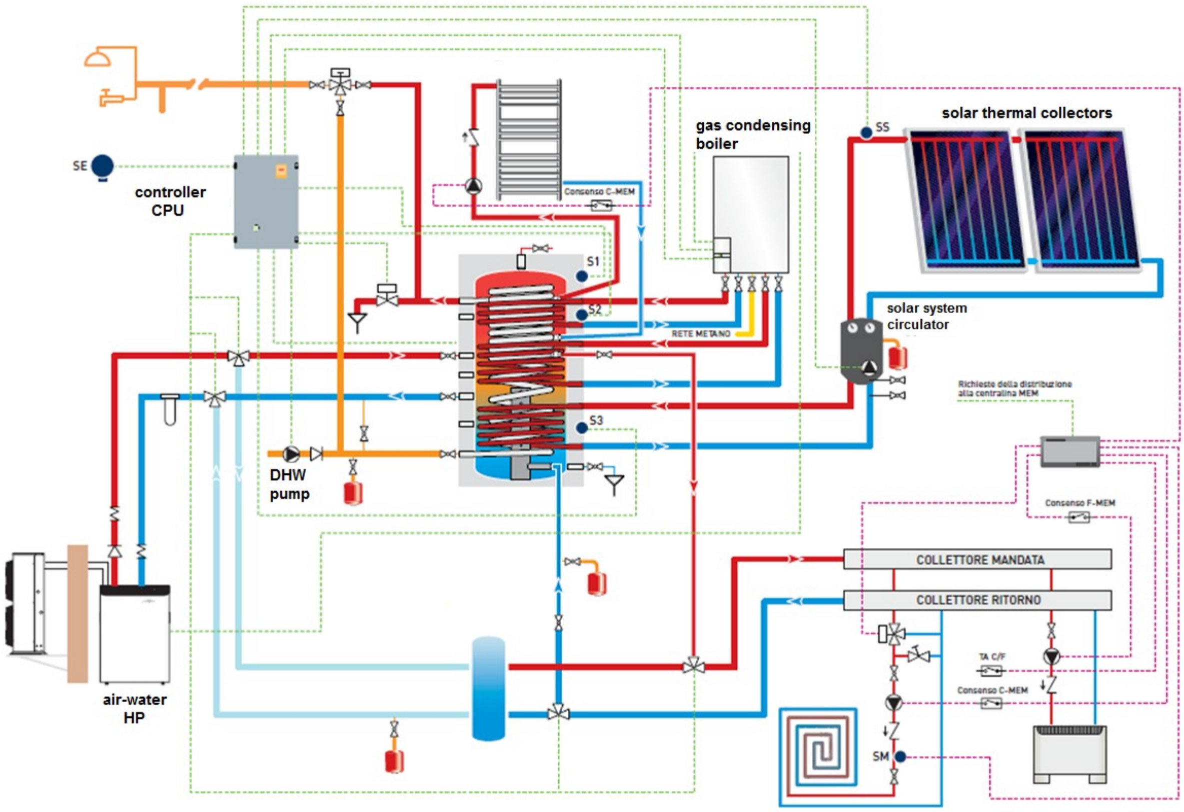


Figure 2.5. plane of the analyzed HVAC system

2.3.3.1 Gas condensing boiler

Boilers can be divided into three types, on the basis of the operative temperature:

- boilers at a constant temperature (high temperature)
- boilers sliding temperature (low temperature)
- condensing boilers

This classification reflects that which is the evolution of heat generators in time. The choice of the type of heat generator and the mode of regulation is critical to obtain high value for the seasonal average efficiency, parameter that, according to regulation, needs to respect certain demands. The Table 2.23, derived from Annex 2 of the Italian regulation D.P.R. 660 of 15 November 1996 for the implementation of the European Directive 92/42/EC, presents the efficiency requirements for new hot-water boilers fired with liquid or gaseous [9]:

Table 2.23. Efficiency requirements for new hot-water boilers according to Italian regulation

Classification	Demanded efficiency at the nominal power (Pn) and at the average boiler-water temperature of 70 °C [%]	Demanded efficiency at 30% partial load (0.3*Pn) and at the average boiler-water temperature of 50 °C [%]
*	≥ 84 + 2 log Pn	≥ 80 + 3 log Pn
**	≥ 87 + 2 log Pn	≥ 83 + 3 log Pn
***	≥ 90 + 2 log Pn	≥ 86 + 3 log Pn
****	≥ 83 + 2 log Pn	≥ 89 + 3 log Pn

Performance requirements to be met both at nominal output and 30% partial load [10].

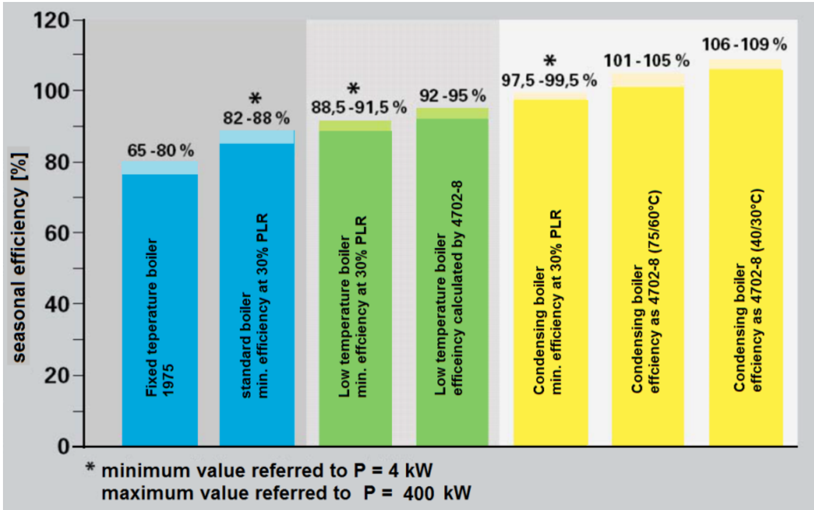


Figure 2.6. Average seasonal efficiency for different types of boilers [10]

The gaseous hydrocarbons include natural gas and refinery gas. These are derived from petroleum refining and include, as a component of greater importance as propane and butane. Natural gases are compounds share decidedly prevailing methane, usually present in percentages exceeding 80%, with lower rates of ethane, propane and butane. The combustion of gaseous hydrocarbons involves the formation of important rates of water vapor. The simplest case (and most important) is that of methane CH_4. Its combustion takes place according to the following elemental chemical transformation:

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ + heat of combustion

The water present in the reaction can be in the form of liquid or steam. In the case are presented both liquid water and steam the heat developed in the reaction is not fully available, since a part of that is spent to raise the enthalpy of the water till the vapor state. Only by cooling the reaction components, commonly indicated in the art such as fumes, to below their dew point, the water vapour can begin to condense yielding the corresponding portion of the enthalpy of vaporization (or condensation). The enthalpy difference that corresponds to the change of state is also defined as latent heat of condensation or, more generally, latent heat of the fumes.

The process of combustion of methane (as of every other hydrocarbon) leads to define two limit values of the amount of heat produced per unit mass of the fuel: the first includes the latent heat of the fumes and takes the name of higher calorific value (PCS) expressed in [MJ/kg], while the second takes account only of the sensible heat of the fumes, thus assuming a value less than the previous, and takes the name of lower calorific value (PCI) that is always expressed in [MJ/kg]. The two values are very different for methane, since the PCS is equal to 55.8 MJ / kg, while the PCI is equal to 50.2 MJ/kg. The greater the difference between the gross calorific value and net calorific value, the greater the possibility of use of condensing technology. For diesel the difference between upper and lower calorific value is 6%, while for the natural gas rise to 11%.

The analysis of combustion refers almost exclusively to PCI, this is because the boilers at a constant and sliding temperature are not likely to operate in condensing the fumes and were just implemented all the possible strategies to prevent condensation. Indeed, in the case of flue gas condensation, there is the formation of substances of strong aggressiveness, first of all the sulfuric acid, with rapid corrosion and devastating against most metals commonly used.

The water vapor begins to condense below the dew-point temperature: this is the temperature at which the partial pressure of the vapor contained in the flue gas is equal to the saturation pressure. In the case

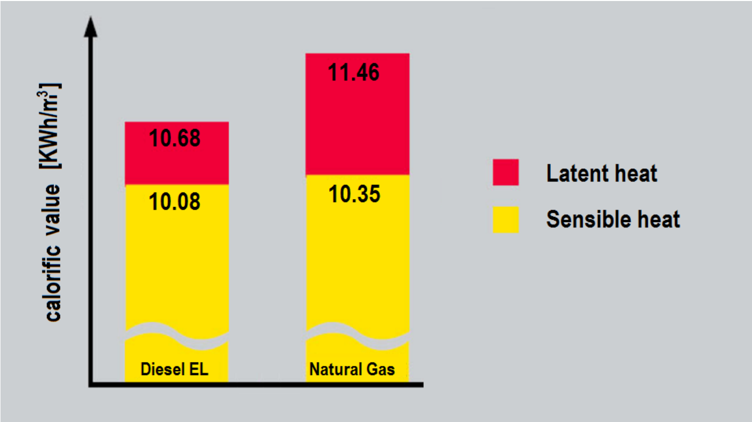


Figure 2.7. *Difference between upper and lower calorific value for diesel and methane [10]*

of a stoichiometric combustion at atmospheric pressure, the value of the dew-point temperature is about 59 °C. In other words, at 59 ° C the content of water vapor in the flue gas is maximum and at a temperature just below, begins to separate into liquid form. In this way the partial pressure of steam lowers (the steam content in the flue gas is reduced) and the saturation pressure is reached at lower temperatures. To be able to condense all the water vapor presented in the flue gas, they should continue to cool.

To better exploit the condensation is essential that the combustion be as near as possible to the stoichiometric ideal conditions in order to maintain a dew temperature of the fumes as high as possible. This allows to easily reach the condensation conditions, and simultaneously to take advantage of a still relatively high useful temperature with which the heating system could be powered. For this reason, in condensing boilers, burners are always kind of blown air and the modulating controls are very sophisticated in order to limit any detrimental air excess.

Referring to natural gas, in ideal conditions stoichiometric condensation start from about 59°C but in the practice it drops around 55°C, because of the excesses of air taken in the new burners.

The graph presented in

Figure 2.8 is very interesting, it indicates the content of water vapor in the flue gas as a function of their temperature and allows to evaluate how much vapor is condensable, given the temperature of the exhaust fumes.

The acidity of the condensate has obviously imposed the use of special materials, particularly the aluminium alloy, that with die casting process has allowed to realize surfaces with great efficiency in heat exchange.

The increase of efficiency in the heat generation is due not only to the heat recovery from the condensate, but also by the fact that cooling the flue gas to below the dew point allows an important recovery of sensible heat of the fumes, assessable at 4-5 points percentages. Condensing boilers allow to lower the flue gas temperature up to about ten degrees higher than the water outlet and ensure a maximum flue gas temperature lower than 85 °C, allowing the use of flues in plastic material (maintained pressure). The efficiency reported to the calorific value, not taking into account the latent heat of condensation in the PCI of the fuel, is greater than the unity; obviously it is lower than unity when referring to the gross calorific value. In addition since the higher yield offered they help to limiting the emissions of CO2 into the atmosphere, and also they have a minimal environmental impact with regard to the emission of nitrogen oxides NO_x, due to the low thermal level of the combustion products.

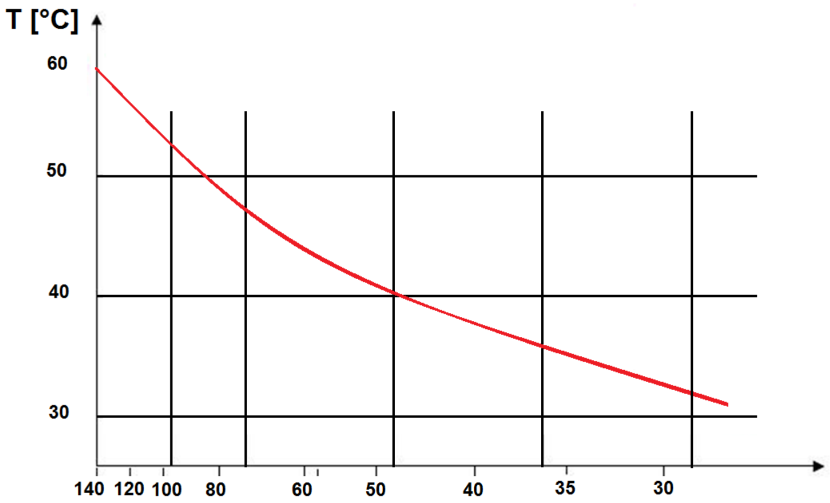


Figure 2.8. Content of water vapor in the flue gas as a function of their temperature

The efficiency of the heat generation is at the present state of technology mainly restricted by the type of heat delivery system, and can reach values of 108% if the system is of the type at low temperature, like as radiant floor or active ceiling.

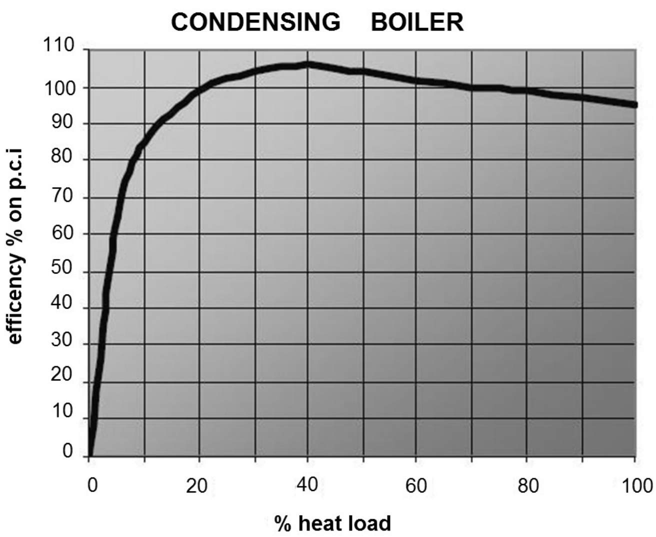


Figure 2.9. Efficiency of a gas condensing boiler respect to the heat load.

Regarding the oil, every speech condensation seems precluded by the presence of sulfur, and therefore safe from the existence of sulfuric acid in the condensate of smoke; also the share of the latent enthalpy is equal to approximately half that of natural gas. Nevertheless, there are commercially diesel boilers made for the condensation, the use of the technique of condensation for the combustion of diesel is distinguished from that for the combustion gas for the following properties:

- the dew point of the combustion gases produced from the diesel fuel is less than 10°C than that of flue gas: the condensation begins later

- the difference between the upper and lower calorific value is 6% in the former versus 11% in the second, then the proceeds of extra energy is therefore less
- the type of design and the choice of materials to be used for the oil condensing boilers are conditioned by the presence of sulfur in the fuel. The condensate must be completely treated by an appropriate neutralization plant.

Condensing boilers are more and more common due to the increasingly stringent regulations in terms of average seasonal efficiency for boilers and because of the effect of the economic incentives existing at the national level.
The boiler considered in the analysis is a wall mounted, natural gas fueled, premixed condensing boiler. It allows a wide modulation rage 1:10, the combustion chamber is sealed and the air flow in forced by a ventilator. Exchanger heater are coiled type and made in stainless steel. The device is equipped with a modulating pump, to guarantee the highest energy performance according to the variability of the heat load. There is an integrates outdoor temperature probe, in order to set the boiler operative temperature according to a climatic regulation profile. The technical features of the boiler are shown in the Table 2.24. The same parameters have been implement in the model of the boiler used for the dynamic simulation carried out to analyze the energy performance of the HVAC system.

Table 2.24. technical features of the considered condensing boiler

TECHNICAL FEATURES		
Thermal power (80-60 ° C)	kW	23.9
Thermal power (50-30 ° C)	kW	26.2
Reduced heat output (80-60 ° C)	kW	2.3
Reduced heat output (50-30 ° C)	kW	2.6
Reduced heat output	kW	2.45/4.0
Useful efficiency min / max (80-60 ° C)	%	93.6/97.5
Useful efficiency min / max (50-30 ° C)	%	107.3/107.0
Useful efficiency at 30% of the load (40-30 ° C)	%	108.0
Energy performance (92/41 EC)		★★★★
Losses arrest at 50 ° C (EN 483)	W	85
Voltage-frequency power	V-Hz	230-50
Electrical power consumption	W	90
CH setting range	°C	20/80
Boiler water	l	4.9
Max working pressure	bar	3
Max Operating Temperature	°C	85
Capacity-pressure expansion vessel	l-bar	8/1
DHW setting range	°C	30/60
DHW flow rate specification (EN 625)	l/min	11.2
Continuous DHW flow DT 30 ° C	l/min	11.4
Minimum flow health	l/min	2
Pressure health min / max	bar	0.2/7.0
Flue gas temperature at max (80-60 ° C)	°C	65
Flue gas temperature at min (80-60 ° C)	°C	51
Flue gas temperature at max (50-30 ° C)	°C	50
Flue gas temperature at min (50-30 ° C)	°C	37
Flue gas flow rate min / max	kg/h	4/41
CO2 flow rate min / max	%	8.9/9.3
NOx class	5 (< 30 mg/kWh)	

2.3.3.2 Solar thermal collectors

The solar collectors achieve levels of efficiency variable on the basis of the plant in which they are installed. Among the solar collectors for low and medium temperature systems such as residential buildings the most commons types are:

- glazed plane collectors
- open plane collectors
- vacuum tube collectors - heat pipe

In the simulations it was decided to implement glazed flat collectors. The plane solar collector (Figure 2.10) can be considered, for simplicity, a heat exchanger that uses the entire incident solar radiation, both the direct and the diffuse to enhance the temperature of a flow of an operative fluid. In particular in plane collectors the absorbent surface is equal to the one that intercepts the solar radiation (aperture surface). The main design parameter in the installation is the area of the collectors needed to produce the heat required. The extension of the collectors field depends on the solar radiation intercepted, on the heat losses of the collector itself, on the heat loss attributable to the rest of the installation and on the use expected for the solar system (DHW generation, space heating or both) .
The process temperatures achievable with flat solar collectors are between 20 ° C and 90 ° C, this justifies their application in the residential sector. The solar panels are fitted with brackets so that they can be stuck on top of the roof tiles ensuring a good anchorage to the roof itself and preventing the infiltration of rainwater; installation in retrofit has the following characteristics:

- it is simple and safe
- it can be performed either with flat-plate collectors that vacuum
- in case of damage of the panels the replacement is easy
- it does not require the interruption of the roof lining
- the additional load is only 20-25 kg/m2 for flat panels and evacuated tubes for 15-20 kg/m2

The main components of a solar collector plan are:

- Absorber: it has the function of receiving the radiant energy, absorb it and transform it into thermal energy. It must have high value of absorption coefficient, low reflection power and high thermal conductivity . Usually metal sheet of copper, aluminum or stainless steel treated is used as absorber with selective coating so that it has high absorption in the solar spectrum and a strong reflection in the infrared in order to make minimum the loss of heat for heating of the surface.
- Transparent cover: it has the function of limiting losses by radiation, it reduces heat losses due to ventilation and natural convection between the absorber and the environment and protects the absorber from atmospheric agents . Usually consists of a glass with low iron content so as to be substantially transparent at low wavelengths and opaque to the infrared radiation emitted by the plate so as to create a sort of greenhouse .
- Heat transfer fluid: it needs to have good thermal properties, in particular, high values of specific heat capacity, cp and of density, ρ, and low viscosity. It must ensure a good frost protection, have not to be corrosive and must withstand the high temperatures that can be reached in the collector in particular conditions.
- Thermal insulation: it serves to reduce the dispersion of thermal energy from the heat exchanger to the outside environment and to control the condensation.

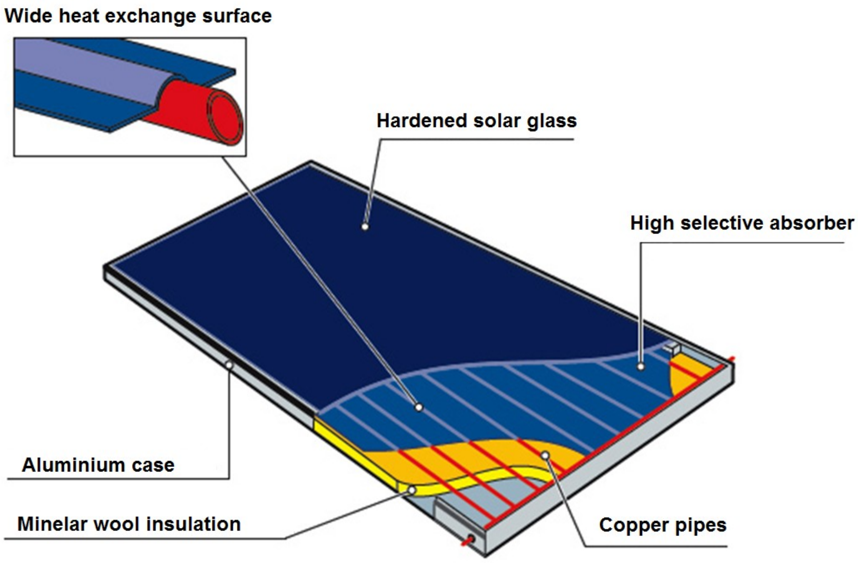


Figure 2.10. Example of a glazed flat solar collectors

The standard UNI EN 12975-2 [11] defines the conditions, the test methods and the accuracy of the instruments to determine the efficiency curve of a solar collector. The efficiency curve could be described by a mathematical relationship or could be experimentally obtained in conditions of approximately normal irradiance to the opening surface of the collector. In Figure 2.11 and Figure 2.12 is plotted the diagrams of the efficiency curve as a function of the average reduced temperature, with reference to a value of irradiance of 800 W/m^2. The results of the test of performance of collectors are provided in certificates, obligatorily supplied by the manufacturer.
The overall efficiency of a solar thermal collector can be expressed by the mathematic Equation (1):

$$\eta = \eta_0 - a_1 \cdot (\Delta\theta/Eg) - a_2 \cdot (\Delta\theta^2/Eg) \quad (1)$$

Where η_0 represent the optical efficiency of the absorber; a_1 and a_2 are respectively the linear and the quadratic coefficients related to the average reduced temperature, that is the temperature difference between the average external temperature and the average of the operative fluid in the collectors; Eg represent the incident radiation on the collector expressed in W/m^2.
The IAM (Incidence angle Modifier) values are provided as well, they describes the variation of efficiency for different angles of incidence of the solar radiation. The IAM represent the ratio between the optical efficiency obtained with irradiance at a given angle of incidence and the optical efficiency in conditions of normal irradiance. IAM are provided for both linear and transversal direction respect to the axis of the collectors; in plane collectors the two set of values coincide but it does not happen for vacuum collectors and heat pipe.
The item used in the analysis and implemented in the dynamic simulation is a plane solar collector equipped with an enriched in magnesium naval aluminum case, it has a 6 cm thickness of mineral wool insulation layer (thermal conductivity of 0.035 W/mK). It has a prismatic glass high resistance of 4 mm and high permeability to light, the absorbing plate is composed of a single sheet of aluminum treated titanium film with selective, laser-welded on the beam copper tube. The absorbing net surface is equal to 2.30 m^2. The collector allows three types of installation (flush, parallel to the slope roof and on flat roof), and the manufacturer guarantees the supply of hydraulic fittings for the installation from

1 to 6 collectors in the same battery. The technical features of the collector modeled in the analysis are shown in Table 2.25.

Table 2.25. Technical features of the plane solar collectors

TECHNICAL FEATURES OF THE PLANE SOLAR COLLECTORS	
η0	0.753
a1	3.91 W/m^2K
a2	0.003 W/m^2K^2
Kθ (angle of incidence 50 °)	0.95
Kθd	0.864
C (heat capacity)	4.8 kJ/m^2K
Peak power	1733 W
Scope of test	180 l/h
Pressure drop at nominal flow	609 Pa (t=20°C)
Tubes in which circulates the heat transfer fluid	1 x Ø22 x 1 x 1065 mm, 1 x Ø22 x 1 x 920 mm, 9 x Ø6 x 0,5 x 1930 m
heat transfer fluid	Water-brine 33.3%
Weight manifold vacuum	50 kg
Volume of fluid in the collector	2.12 l
Number of transparent covers	1
gross area	2.505 m^2
Area of Operation	2.317 m^2
height	2010 mm
length	1260 mm
depth	110
Diameter attacks link	22 mm
Maximum operating pressure	6 bar
Maximum stagnation temperature	201 °C
isolation	Mineral wool (thickness 60 mm)
The containment enclosure	Alluminium
International Standard	Solar collector tested according to UNI EN 12975

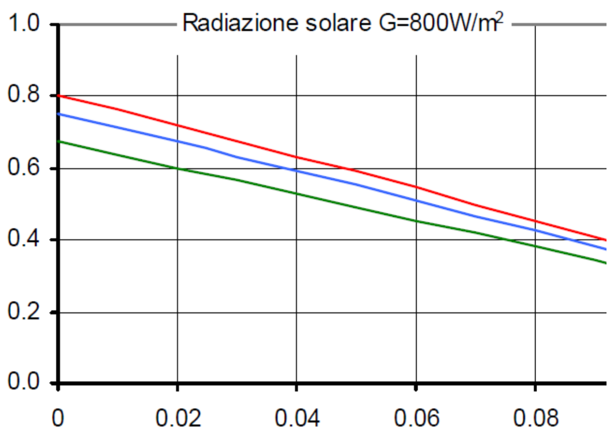


Figure 2.11. efficiency curve as a function of the average reduced temperature

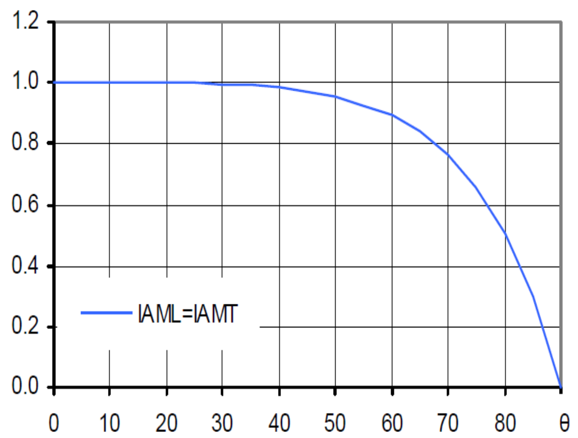


Figure 2. 12. IAM , Incidence angle Modifier values

In Figure 2.11 and Figure 2. 12 are shown respectively the developments in the overall efficiency of the collectors, according to the reduced temperature variation and at a standard value of the incident radiation, and the values of the IAM longitudinal and transverse values. Note that the incidence angle modifier has practically no influence at angles of incidence which vary up to 20° from the horizontal.

Is usual in the certification to report only the value of the modifier of the angle of incidence for an angle of incidence of 50°.

2.3.3.3 The heat pump

A heat pump is a device that draws heat from a source at a lower temperature and makes it available, together with the equivalent thermal energy used to make this operation possible, for external use at a temperature higher than average. The name of the heat pump therefore derives from the operation of elevation of the level of thermal energy available as heat, and is of course useful operation when the thermal energy is made usable in higher temperature than that of the external environment, in this context we speak of thermodynamic heating.

It is straightforward to observe as from the point of view of the operating principle there are no differences between a refrigerating machine and a heat pump: the difference lies in what constitutes the useful effect of the installation, ie the removal of heat from a system at a temperature lower than the ambient temperature in the refrigeration system and for the transfer of heat to a system at a temperature higher than room temperature for a heat pump. Consequently, only the temperature ranges within which they operate refrigeration systems and heat pump are different. There are rare cases in which a machine acts simultaneously as a refrigeration system to the cold heat exchanger and as heat pump to the hot heat exchanger: in this case, the temperature range of operation is around the temperature of the room in which the machine is placed.

So it is not surprising that referring to heat pumps the thermodynamic cycles ideal reference are the same (in a different context of temperatures) of refrigeration equipment ones; with the exception of those more properly adapted to operate with large difference temperature between the hot source and the cold source. In this situation could be there are not economic advantage in the use of a heat pump instead of the direct use of the heat generated by combustion of traditional fossil fuels.

The energy performances of a heat pump are evacuate by the means of a parameter called coefficient of performance (COP), defined by the mathematical Equation (2)

$$COP = \text{useful energy effect} / \text{energy cost to achieve the useful effect} = q / P \qquad (2)$$

Where q is the heat flux available at the condensing unit of the device and P is the electrical power needed by the compressor to complete the thermodynamic cycle.

For heat pumps whose operating conditions are variable over time, for example because of the variability of the climatic conditions of the external environment, the COP can be defined as a average value of the coefficient of useful effect, using, in the previous expression ,the corresponding temporal average values for the mechanical power and the thermal flux made available. Moreover the consumption associated with complementary operations can be taken into account, such as the periodic defrosting of the evaporator when the heat source is the outdoor air temperature and its value is below zero centigrade degrees.

Often it is useful to compare the COP of the considered heat pump with what the same machine would have, operating under the same temperature conditions, but following an ideal Carnot cycle. The Carnot efficiency expresses the maximum value ideally achievable for the coefficient of performance, and it is the value to which the COP of a real installation should tend. In practice, in the typical operating conditions of the heat pumps, the value is much lower than the ideal one, influenced by both the temperatures of the cold source and of the hot reservoir.

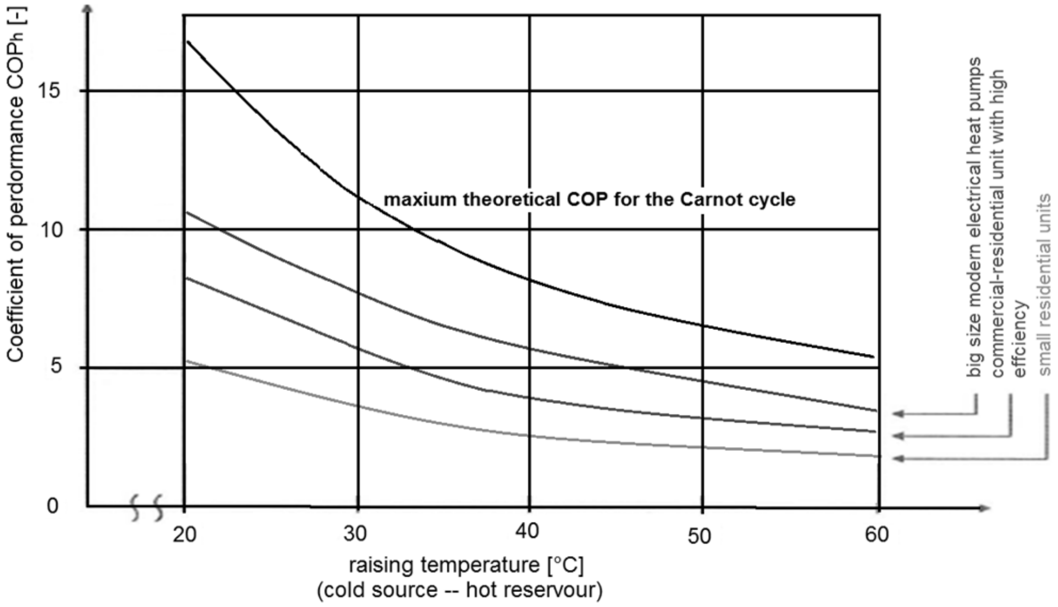


Figure 2. 13. Typical COP according to size of the heat pump and to the temperature difference of their operation

The analysis of the convenience of heating through a heat pump rather than with direct combustion of fossil fuels, requires the consideration of several technical-economic factors not easily generalizable. In terms of primary energy savings it can be observed, referring to heat pumps dragged by electric motors, that each unit of electric energy needed is equivalent to 2.17 units of thermal energy converted from fuel in a thermal power plant. This considerations takes into account not only the conversion efficiency of the system, but also the losses in processing and distribution of electricity. Considering only the primary energy savings, the convenience for the heat pump is greater the more it operates with a coefficient of performance value COP > 2.17.

The component modeled into the simulations is a air-water interface heat pump, with the external condensing unit distincted from the inner part which contains the hydronic circuit and compressor. The machine allows three levels of power output according to type of the elecrical connection: single-phase connection 3-8 kW and 3-12 kW, and 6-33 kW three-phase connection. The refrigerant fluid is R410, the compressors are the type Rotary Twin-Scroll with permanent magnet synchronous motors and variable speed. The machine is equipped with hydronic pumps and variable speed fans, and brazed plate heat exchangers and has a built-in defrost.

Table 2.26. Technical features of the heat pump

TECHNICAL FEATURES OF THE HEAT PUMP				
Compressor rpm		min		max
Thermal power	kW	2.1		5.6
Compressor power input	kW	0.6		1.8
Current consumption compressor (230V/400V)	A	3.0		8.5
Power Consumption fans	kW		0.1	
Current draw fans	A		0.5	
COP	-	2.99		3.07
Flow of water users	kg/h	363		980
Water pressure drops users	kPa	<5		6
Prevalence useful water users	kPa	67		63
Air flow dissipation	m^3/h		3500	

The Table 2.26 shows the technical data of the air-water heat pump selected for the analysis and the temperature level for the operating conditions.The design operative conditions in heating conditions are:

- outside air temperature: -5 ° C
- inlet water temperature: 35 ° C
- outlet water temperature: 40 ° C

2.3.3.4 Thermal storage tank

The accumulation tank is an important component of the energy system which has the task of compensating the time lag between the availability of the heat generated by the boiler, the generation of heat through the solar system and from the heat pump and the heat demand from the users, i.e. the heat load. The time compensation is managed by storing the heat in a fluid, typically water in the liquid state, into a insulated steel tank. The accumulation must be designed in the context of the energy system used, i.e. considering the carrier fluid in use, the working temperature, etc.

The main features and parameters to be evaluated for a thermal reservoir are:

- thermal capacity per unit volume or per unit weight;
- stratification;
- operating temperature range;
- methods of heat exchange inlet and outlet and the associated temperature drops;
- auxiliary energy needs for the introduction or removal of stored energy;
- structural elements;
- methods for the control of heat loss from the system;

The materials commonly used for the construction of a storage tank are stainless steel and aluminum for the structure and the polyurethane thermal insulation. To achieve good water quality, must be made a suitable anti-corrosion treatment for food suitability, as specified in the technical standards EN 12975-1, EN 12976-1[12] and EN 12977-1[13].

The optimum capacity of a tank is influenced by the temporal variation of the demand for hot water and heating and by administration auxiliary energy. The most common storage medium is water, due to its good quality in terms of specific heat capacity, viscosity, thermal conductivity, density, also is not toxic nor flammable, remains in the liquid state in the range of desired temperatures and is very economic .

Inside the tank occurs the phenomenon of layering, ie there is the formation of temperature levels well differentiated, with the upper warmer than the bottom, due to the density difference. This process is very useful because you want to send to the services the hottest water possible and transmit the solar collectors water as cold as possible to increase their productivity. A method for achieving the stratification consists in making use of low values of flow, so that you have small entrances and exits of the fluid in comparison to the accumulation volume and at low speeds. Furthermore, we must carefully choose the input and output points of the fluid, using specially designed dispensers.

A low thermal stratification has as consequences of the accumulation:

- the maximum temperature of the available water is lower respect to a situation with a good stratification inside the tank
- the mixed zone, characterized by an average water temperature, is more extensive

- the thermal energy obtained has lower quality: the exergy of the water is lower
- accumulation is less efficient: the auxiliary heating system intervenes more frequently and at partial load

The accumulator must be designed so that the heat exchangers in which flow the streams of water can be incorporated as well as the measuring instruments for temperature and pressure . Also here is the need to have an access for cleaning and emptying the inner volume.
The component included in the model under analysis is a thermal storage operating in stratification for the production of domestic hot water and for heating, optimized for applications multi-energy. An image of the device is provided in Figure 2.14, while dimension and features are provided in Table 2.27 and Table 2.28. The mantle is made of carbon steel S235JR and is insulated by a coating of polyurethane foam, CFC-free HFC, covered with a PVC sheath.
The storage tank is equipped with:

- immersed coil in AISI 316 stainless steel, with corrugated surface for the preparation of hot water, a capacity of 48 liters, capable of ensuring the non-proliferation of legionella as Standard DVGW-W551;
- coil for connection to solar collectors;
- coil for connection to the boiler;
- coil for connection to a source of additional heat;
- connection for thermo furnishings;
- connection for thermo fireplace;
- connection facility for low temperature;
- return stratifying S235JR carbon steel pipe to ensure a better temperature stratification;
- inside the storage tank, free admission 1 1/4 "and 1 free admission half;
- provision for the housing 4 wells and 2 connections 1 1/2 "free.

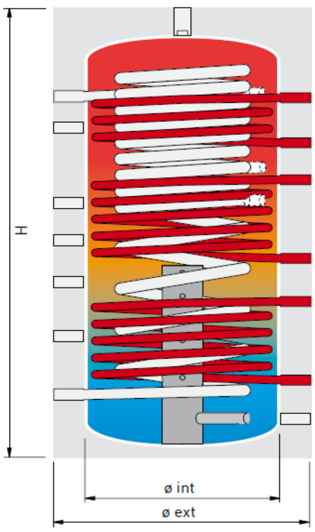


Figure 2.14. Section of the thermal storage tank

Table 2.27. Dimensions of the thermal storage tank

DIMENSIONS	
H [mm]	1720
Øint [mm]	650
Øest [mm]	850

Table 2.28. Technical features of the storage tank

TECHNICAL FEATURES OF THE STORAGE TANK		
Tank volume	l	500
Weight empty	kg	210
Full weight	kg	710
Construction material		S235JR
Soft polyurethane insulation	mm	100
Thermal conductivity insulation	W/m^2K	0.0426
Maximum operating temperature	°C	95
Thermal losses at t = 45 ° C	W/l	0.361
Material tube stratifying		S235JR
PERFORMANCE DHW GENERATION.		
Charging time from 15 to 60 ° C - 30kW	min	25
Charging time with drawing 860 l / h - 30kW	min	10
Withdraw 15 l / min at 45 ° C - 60 ° C	l	342
flow rate 20 l / min at 45 ° C - 60 ° C	l	257
flow rate 25 l / min at 45 ° C - 60 ° C	l	206
Max operating pressure tank	bar	3
Max operating pressure coil A.C.S.	bar	10
Max operating pressure coil	bar	10
DHW COIL		
capacity	l	48
Exchange surface	m^2	5.64
standard flow rate	l/h	-
SOLAR COIL		
capacity	L	18
Exchange surface	m^2	2.34
standard flow rate	l/h	200
INTERMEDIATE COIL		
capacity	L	18
Exchange surface	m^2	2.3
standard flow rate	l/h	1000
TOP COIL		
capacity	L	10
Exchange surface	m^2	1.3
standard flow rate	l/h	1000

2.3.3.5 Controlled Mechanical Ventilation

In residential buildings the indoor air is continuously polluted by odors, carbon dioxide, water vapor . It is essential to evacuate the contaminated air for reasons of comfort, hygiene and health. In homes not airtight, the daily aperture of windows and the air leakages between the walls and the frame ensure a consistent renewal of air. This natural ventilation of the building guarantee often a good quality of the indoor sir, as long as the windows are open frequently, but on the other face it implies ah high energetic cost due to increasing energy consumption required for the indoor space heating. Nowadays, with the aim of energy saving, the buildings are equipped with high-quality windows and doors that make them very impermeable to the outside air, the only way to ensure a renewal of air with a perfect flow control is through a controlled mechanical ventilation system (CMV). Furthermore, the excessive concentration of vapor in the air generates condensation on the walls, and if it is prolonged in time it could comport the formation of unsightly as unsanitary mold or stains. In the worst case it could lead to the deterioration of structures. The water vapor content in the air of residential building has mainly two origins :

- Technical origin: in the kitchen (cooking food , dishwasher, iron), laundry (use of toilets, showers, laundry to dry);
- Human origin : each person produces an average of 1,150 kg of steam d ' water a day.

When the air with a high content of steam water reaches the saturation conditions and it is in contact with a cold wall the phenomenon of condensation occurs .
The systems controlled mechanical ventilation (CMV) are technologies that allow continuous ventilation of residences, controlling the flow of fresh air according to the requirements specified in the design phase . They are essentially based on the concept of reducing as much as possible the development of networks or air distribution systems to maintain low the cost of installation, such as small diameter rigid or flexible channels. CMV systems meet the following requirements:

- ensure air flow injection / extraction, in quantities;
- ensure the possibility of varying the airflows as a function of the ambient conditions (increase or decrease of indoor air humidity, presence or absence of people, etc.).
- ensure the possibility of air filtration (in dual flow);
- offer the possibility of heat recovery from the exhaust air (in dual stream)

There are different types of systems controlled mechanical ventilation:

- mechanical ventilation systems to simple extraction flow for fixed flow;
- mechanical ventilation systems to simple extraction flow for variable hygro-adjustable flow;
- mechanical ventilation systems with dual-flow heat recovery static or thermodynamic.

The principle of ventilation of a residence, as shown in the Figure 2.15, is to provide fresh air in rooms with low production of pollutants, such as living rooms and bedrooms, and the simultaneous extraction of stale air from the areas with the highest concentration of pollutants, such as kitchens, toilets, and if present, laundries.

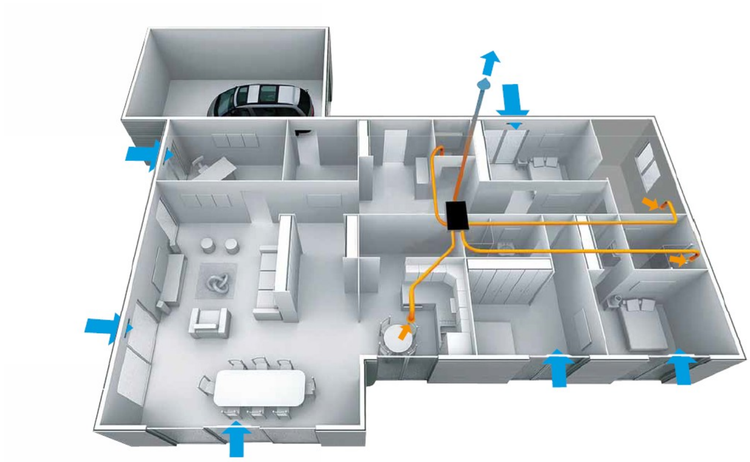


Figure 2.15. Principle of the ventilation of a residence

In the case study it was decided to model a plant family with dual flow ventilation and heat recovery (Figure 2.16).This solution is the development of systems to simple flow in terms of air quality, energy conservation and welfare. The air drawn from outside is previously filtered before being introduced into the environment, and the cross-flow static heat exchanger ensures the preheating of the fresh air in winter conditions. The dual-flow solution also allows the control of the air flow rates for individual zones, installing ventilation self regulating outlets. In this case the inflow of air takes place via a fan and a network of small diameter channels and via the relative nozzles input; the air extraction takes place as in the previous cases.

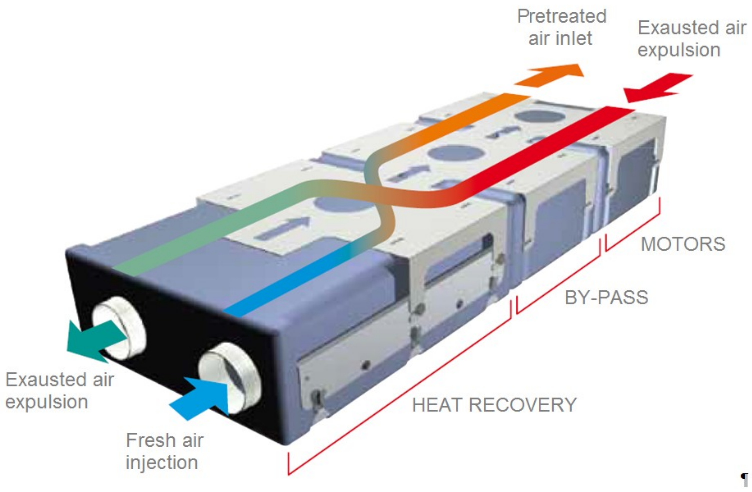


Figure 2.16. Dual flow ventilation system with heat recovery

The use of mechanical systems in residential buildings contributes to the containment of heat due to the processes of ventilation. The opening of the windows, contrary to popular belief, has been evaluated as the most energy expensive mode of ventilation, as the flow rates of air changes cannot be controlled and, even during the short periods of the windows opening, in the winter conditions the heat losses are very high. Energy studies have asset to natural ventilation the average of1.2 Vol/h for the air change value during the opening of the windows, against standard values of the mechanical systems of 0.5 Vol/h, that are considered optimal even to maintain the indoor air quality.

2.4 The Simulation: Software and Model

2.4.1 The model of the building

The Commercial software TRNSYS[13], provided by " Solar Energy Laboratory of the University of Wisconsin -Madison ," is a comprehensive and flexible platform used for the dynamic simulation of power systems. The scope of TRNSYS is vast and includes every type of system energy: solar, photovoltaic, HVAC systems, renewable energy, fuel cells, etc.. Key features of the software is its modular structure and its code open source programming, which gives users the ability to edit existing templates or create new ones to suit your needs through the most common programming languages (C, C + + , PASCAL , FORTRAN , etc. .) .
TRNSYS consists of a suite of integrated programs, between them: the TRNSYS simulation study, TRNDll.dll the simulation engine and its executable TRNExe.exe; the graphical interface that allows

you to enter the input data of the building, the TRNBuild.exe; l' editor used to create programs and subroutines TRNEdit.exe . In addition, TRNSYS can easily exchange information input-output connecting to other software and applications (Microsoft Excel, Matlab, EES, Etc. .). TRNSYS is used worldwide by engineers and researchers for pre or post processing operations to demonstrate the validity of new conceptions of energy .

The model of the analyzed building was implemented by the TRNBuild program, using the multi-zone building type. The word “type” in TRNSYS code refers to models and subroutines used to implement several different items: from entire buildings, to machines like as boilers, heat pumps, solar collectors, or devices like as pumps, ventilators, valves, mixers, etc..

TRNBuild allows the operator to implement the geometrical and physical characteristics of the building envelope, the settings for the climate control and for the comfort conditions, the presence of solar and internal heat gains and contribution of the interactions with the external environment.

The modelization of the building was done according to the following step design:

- definition of the orientation of the building
- definition of the thermal zones
- definition of the surfaces associated to the external faces of the building
- entering the necessary data to calculate the variables of the system
- description of the building structures
- description of the glazed components

The first step in the modeling of the building consists into the definition of the number of thermal zones. The distribution of the internal environment through active and inactive thermal zones is a choices of the operator: zones could not coincide with single rooms but could also collect several areas of the building, In the case study three thermal zones have been defied, one for each floor of the building. The label used for each one is :

- GROUND FLOOR
- FIRST FLOOR
- ATTIC

After the creation of the thermal zones, it is necessary to assign them the surfaces that enclose the inner volume. Whit the term surface walls, roof and floor are included as well as relative windows. Each surface must be properly allocated in the space of the building with its sizes (gross area [m^2]), and it has to be define whether it is external, internal, adjacent or " boundary" wall . An external surface is the separation wall between the thermal zone and the external environment, is associated to the facade of the building and it must be described according to its orientation respect to the spatial cardinal axes and its tilt respect to the horizontal reference plane. These parameters are used in the evaluation of the view factor of the wall for calculations regarding the solar radiation and solar gains and the radiant thermal exchange with the environment. An internal surface is simply representative of a partition wall, it influences the zone thermal capacity. An adjacent surface is a separation wall between different thermal zones of the building: these surfaces will be common two thermal zones, and when implemented to a thermal zone it will be copied on the corresponding adjacent zone. Last, a boundary surface, is a structure in contact with an environment whose characteristics are stated by the users, as occurs, for example, to the basement whose perimeter walls are generally considered as bordering to a homogeneous surface at the soil temperature.

After the definition of the thermal zones and of the surfaces form which they are limited, the construction of the model requires to proceed filling the initial condition necessary for the software to calculate the variables of the system. Parameters related to heating, cooling, ventilation, infiltration, humidity, internal, loads, comfort need to be implemented. The design parameters of the system can be supplied in three ways: by a constant value of he set-point, by the means of a programmable daily or weekly schedule, and by the connection with an external input text file. The values used in the simulation of the case study are presented subsequently in the discussion of each set of parameters implemented.

The surfaces, mentioned above in order to delimit the thermal zones, shall be described according to their stratigraphy . At this stage it is possible to use the elements present in the library of materials, or, in order to maintain a better adhesion between the model and the case study, it is possible to create ad hoc layers, on the basis of the characteristics of real walls. To do this the operator should use the tools "Layer Type Manager " and "Wall Type Manager ", which allow to model the walls of the building through the description of each single layers that compose the walls. In the "Layer Type Manager "the operator shall provide for each layer the values of thermal conductivity [kJ/(hmK)], of the specific heat capacity [kJ/(kgK)] and of the density [kg/m^3]. Then in the " Wall Type Manager " the operator specifies the thickness [m] of any layer. The software calculates the total values of the thickness and of the heat transfer coefficient [W/m^{2}K] of the opaque. Proper values for the internal and external liminal coefficients are considered as well, respectively α_i = 7.7 W/(m^{2}K) and α_e = 25 W/m^{2}K). The different surfaces implemented in the model have been created according to the physical property and the stratification of the real walls, please refer to paragraph 2.3.1 for the detailed description.

To complete the model of the building the operator needs to implement the windows and other eventual glazed elements. The suitable tool for this task is the "Window Type Manager", which requires some geometrical data like as the gross area of the frame [m^2], the surface of frame [m^2] and the thermal characteristics like as the heat transfer coefficient [W/m^{2}K], the g-factor of the glass, etc..

2.4.2 The model of the HVAC system

The modelization of the HVAC systems has been realized by the means of the TRNSYS sub-program Simulation Study. This phase of work is very complex because the interaction between the different components of the system requires special attention in the association between the parameters and variables of the devices. Since the creation of the project is very laborious, the following is the description of only the main steps.

A project in TRNSYS Studio is built by composing models of the various components, selected from the library included within the workspace, then the components are connected graphically and numerically according to the relations of cause and effect and the real plant interactions. Finally, the general parameters of the simulation have to be set, such as the duration of the analysis step of the simulation, the values of tolerance and convergence for the transfer functions.

Each "type" (component model) is described by a mathematical model and requires a certain number of parameters, input and output values, could need external files in text format from which to draw input data. The operator cam enter functions and parameters manually or by using different computer codes depending on the complexity of the operation to be performed. External programs are not included in the TRNSYS platform, but several codes can work coupling to it.

Finally, the parameters necessary to run the simulation are implemented within the window "Assembly - Control Cards"; like as :

- time of start and end simulation [h]

- simulation time step [h]
- solution method
- tolerance of integration [-]
- convergence tolerance [-]
- maximum number of errors allowed
- other settings

More information according to the implementation of the HVAC model are presented in the paragraph dedicated to each simulated case study.

2.5 Simulations: Methods And Discussion

2.5.1 CASE "0": the ante-opera

2.5.1.1 Methods

The situation "ante-opera" of the existing building can be easily described. The building envelope is not sufficiently isolated (Table 2.29), as the thermal transmittance values for the surfaces facing outward (as shown in the stratigraphy) are considerably higher than the limit values set out in Annex B of the Italian Decree of 26 January 2010 relating to the climate and the property of building in the climatic zone E [14]. The poor state of the building affects both the properties of the enclosure, both the plant components and operation of the heating system.

Table 2.29. Status of the building envelope before the retrofit

	ANTE OPERAM VALUE [W/m^{2}K]	**THRESHOLD VALUE [W/m^{2}K]**
Pitched roofs	2.74	0.24
External walls	1.41	0.27
Windows	2.84	1.80

The infiltration air rate, in normal conditions, has been evaluated in 0.3 Vol/h. This value includes both the air infiltration through doors and windows and the renewal air rate due to the daily opening of the windows. The ante-opera situation does not present any mechanical ventilation system controlled.
The heated zones are part of the ground floor and the entire first floor, while the garret is not.
The energy for heating and production of hot water is entirely provided by a conventional sealed chamber gas boiler, classified as C type ⋆ ⋆ ⋆ (3 stars). The boiler has a nominal power rate of 25 kW, it works with a set point temperature of 75°C and the regulation mode is regulated according to the average temperature of the thermal zone and operated with an ON / OFF controller. The HVAC system terminals for the heat emission are radiators, the flow delivery temperature is constant and set to 70°C and the flow rate is equal to 1500 l/h. The set point temperature in the heated zones is 20 °C and the system turns on intermittently for a total of 14 hours per day.
The simulation of the building in operative conditions, taking account also of the internal gains due to people and electrical devices, provide a quite precise description of the behavior of the building in heating and cooling conditions, concerning the indoor temperature of each thermal zones and the energy needs in order to maintain the set point temperature, and the desired levels of relative humidity.

To pass from the building energy needs to the energy that must provide by the HVAC system proper values of the overall seasonal efficiency have to be defined. These values can be derive the Italian regulation UNI / TS 11300-2. According to the case studied the values assumed for the analysis are:

- efficiency of the emission system → $\eta_{em} = 0.88$,
- efficiency of the regulation system → $\eta_{reg} = 0.93$,
- efficiency of the delivery system → $\eta_{del} = 0.974$,
- efficiency of the generation system → $\eta_{gen} = 0.92$.

To better understand how the model of the HVAC system has been implemented and how it has been connected to the model of the building some sketches of the simulation studio working space are presented. The Figure 2.17 shows the section of the model concerning with the conventional boiler. The connection between the boiler and the thermal tank can be observed, as well as the interaction with the controller with ménages the operation of the boiler on the basis of the temperature of a probe place at a desired height of the tank. The component of this section are: the boiler, the water pump and the regulator.

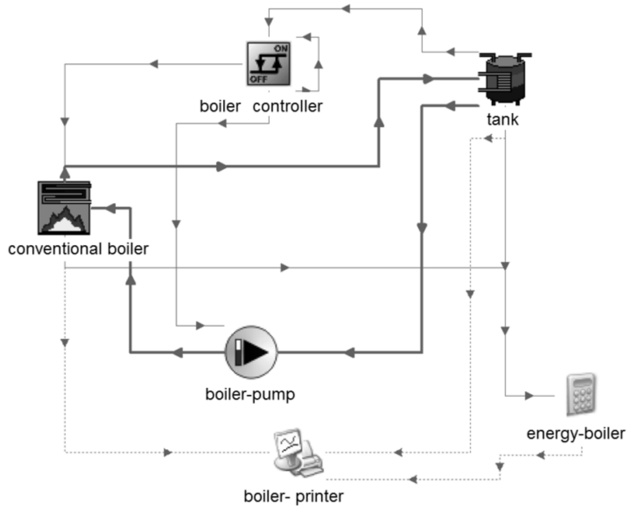


Figure 2.17. Model description - Boiler circuits

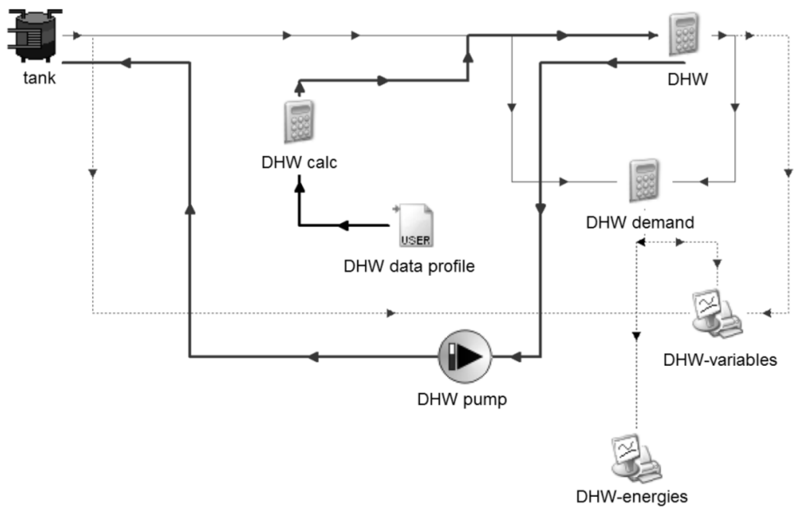


Figure 2.18. Model description - DHW circuits

The Figure 2.18 presents the circuits for the DHW generation. The components included in this section are: a circulation pump and a calculator that simulates the operation of a 3-way valve.
The Figure 2.19 shows the heating section of the HVAC systems, according to the generators and the delivery system to the building. The involved components are: thermostatic valve, pump, delivery system and calculator that manages the operation of the terminals of the emission system. It should be noted that the thermal storage is not physically present in the plant but is has been inserted into the worksheet with the aim to simulate the operation of a normal hydraulic manifold.

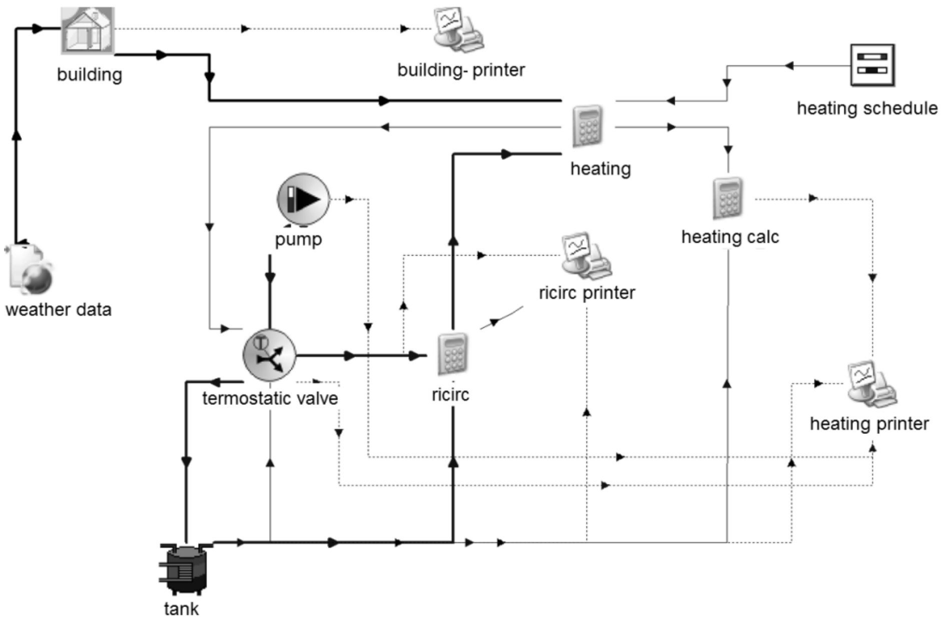


Figure 2.19. Model description - Heating circuits

To run the simulation the program have to be provided with external files containing the climate data, the indicator of the heating season, the data of the average profile for the DHW consumption in the residential building. Calculators for the determination of the energy requires have to be provided, as well as printers for graphical display of the results.
The project was built with the following logic: the building (type 56) receives the climatic data contained in the library of TRNSYS and related to Marco Polo Airport , which is the closest available set of climatic data respect to the case study (type 15). The building, interacts with the environment and the the TRNBuild tool provides the temperature and the fluxes of sensible heat, needed to offset losses and maintain the set point conditions inside the building, to the calculator "heating". This type evaluates the building energy needs, the temperature of the water delivered and calculates the temperature of the return water flow to the collector of the system. The flow rate of the heating plant is assumed constant, and it is stated by the pump (type 110) which is connected to the fictive thermal tank (type 534) . The calculator “heating calc” simulates the operation of a 3-way valve and determines which portion of the flow rate, from the return of the heating system, have to be ricirculated in order to guarantee that the temperature of the delivery water flow matches the set point value. To optimize the operation of the heating circuit everything is coordinated by the set point temperature imposed by the thermostatic valve "thermostat" (type 11) and by the value of the on/off indicator of the heating season "heating schedule " (type515).

At the same time the request for sanitary hot water is managed by the calculator "HDW" , which determines the flow to be deliver to the tank by a mass balance between the flow rates required to satisfy the user at the temperature of 40° C.

The energy requirements for the hating and for the DHW generation circuits are covered by the heat generator (type 751). The set point temperature is imposed in the input data of the type, together with the nominal power, the specific heat capacity of the fluid. The boiler is connected to the tank by the means of a pump and it is managed by an on/off type controller (type 2). The controller needs to be set with the value of temperature that has to be controlled, the minimum value allowed and with the amplitude of the upper and lower dead bands, and provide a logical control function used to switch on or off the device. The Table 2.30 resumes the data and the parameter used in the simulation of the CASE 0.

Table 2.30. Data and the parameter used in the simulation of the CASE 0.

SIMULATION DATA AND PARAMETERS CASE 0: ante opera		
BUILDING		
Transmittance coverage	W/m^2K	2.74
Transmittance of exterior walls	W/m^2K	1.41
Transmittance windows	W/m^2K	2.84
Infiltration	Vol/h	0.3
HVAC SYSTEM		
Traditional boiler		
Power Rating	kW	25
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Temperature set point	°C	75
Generation efficiency η_{gen}	-	0.92
VENTILATION		OFF(natural ventilation)
BOILER CONTROLLER		
Th (upper temperature input)	°C	70
UDB (upper dead band)	°C	5
LDB (lower dead band)	°C	2
SYSTEM TERMINALS		
Radiators		
Nominal flow	l/h	1500
Flow temperature	°C	70
GENERAL		
operation mode		intermittent
Ignition hours per day	h	14
Emission efficiency η_{em}	-	0.88
Regulation efficiency η_{reg}	-	0.93
Distribution efficiency η_{distr}	-	0.974

Running the simulation, then, it is possible to calculate the amount of energy exchanged within the HVAC system and the building. In the case study a period of analysis 1 year has been considered, from 1st January to 31st December. To increase the accuracy of the results obtained and eliminate the initial transient, simulations were performed over a period of two years , taking as useful values for the calculations the ones concerning the second year .

Several entities have been evaluated, according to their absolute values [kWh] and in specific values [kWh/m2], in order to achieve a complete description of the energy behavior of the system, such as:

- dispersions through the building envelope , ie the ideal net energy requirement necessary to maintain the indoor set point temperature of 20 °C
- thermal energy demanded for heating to the HVAC system , ie the actual needs that takes account of the losses for emission , regulation and distribution
- thermal energy required demanded for the production of sanitary hot water
- heat supplied by the boiler to cover the energy requirements and losses
- global energy required to meet the energy needs of the building , plus taking into account the loss of generation
- power absorbed by the auxiliaries (circulation) of each circuit
- primary energy

In the simulations the energy losses in the sub-emission regulation and distribution have already been taken into account, therefore, to derive the total thermal energy required to meet the needs of the building for heating and domestic hot water generation it is sufficient to divide the amount of energy provided by the heat generator by its generation efficiency. To go back to primary energy must then take into account the conversion factors, respectively from thermal energy to primary energy and to electricity to primary energy the values presented in Table 2.31 have been used.

Table 2.31.Conversion factors for primary energy

Efficiency associated with fossil fuels	90%	→	1 kWh_t = 1/0.9 = 1.1 kWh_{EP}
Efficiency associated with the electricity grid	46%	→	1 kWh_{el} = 1/0.46 = 2.17 kWh_{EP}

2.5.1.2 Results

The results of the simulation carried out for the CASE 0 are resumed in the Table 2.32. The case analyzed refers to the condition of the building and of the plant before any retrofitting action.

Results show how the thermal energy lost through the envelope assumes a conspicuous value, mainly according to the transmission term. The outcome is coherent with the expectations of the simulation results in the ante-operam situation, considering the high U-value of the external surfaces of the model and the peak value recorded to the heat dispersions that is equal to 16.9 kW.

The energy generated by the HVAC system is greater than 20.9% compared to the heating and DHW energy demand. This increase is due to the effect of the thermal yield of subsystems, considered together as the overall coefficient performance of the plant. Particularly great effect has the low emission efficiency value associated with radiators installed on exterior walls are not insulated, and the poor regulation efficiency of the on/off controller based on a single indoor temperature.

In Table 2.32 are presented the total energy required to the thermal tank and the total energy supplied from the boiler to the storage. Because of the energy balance the two values should coincide but in reality they have slightly different values, with a deviation of 6%. This difference is related in minimal part to the tack thermal losses (which has proved to have a very low value according to the other terms of the energy balance), but especially depends on the intrinsic error related to the calculation code. An error of about the 5% is actually a good results considering the temporal extension of the simulation and the complexity of the analyzed system.

Table 2.32. Results of the simulation carried out for the CASE 0

CASE 0	**kWh**	**kWh/m²**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	23778	112.69
transmission	19214	91.06
ventilation	4564	21.63
Energy demand for heating (include the overall efficiency of the system)	28753	136.27
Energy demand for DHW	3418	16.20
Total energy demand recorded at the tank	32172	152.47
Total energy supplied from the boiler to the tank	34226	162.21
Total demand of thermal energy	37202	176.31
Power absorbed by auxiliaries	739	3.50
circulation pump boiler	79	0.37
heating circulation pump	393	1.86
DHW circulation pump	267	1.27
Primary Energy	38806	183.91

For a more detailed analysis of the results charts of the monthly energy needs are presented as well. The Figure 2.20 shows a comparison among the thermal energy need of the users, divide in heating and DHW generation, respect to the energy provided by the conventional boiler. The Figure 2.21 presents the primary energy demand during the year of analysis, the energy provided as fossil fluid is the prevailing term, while the auxiliary power supply term only a few percent of the total.

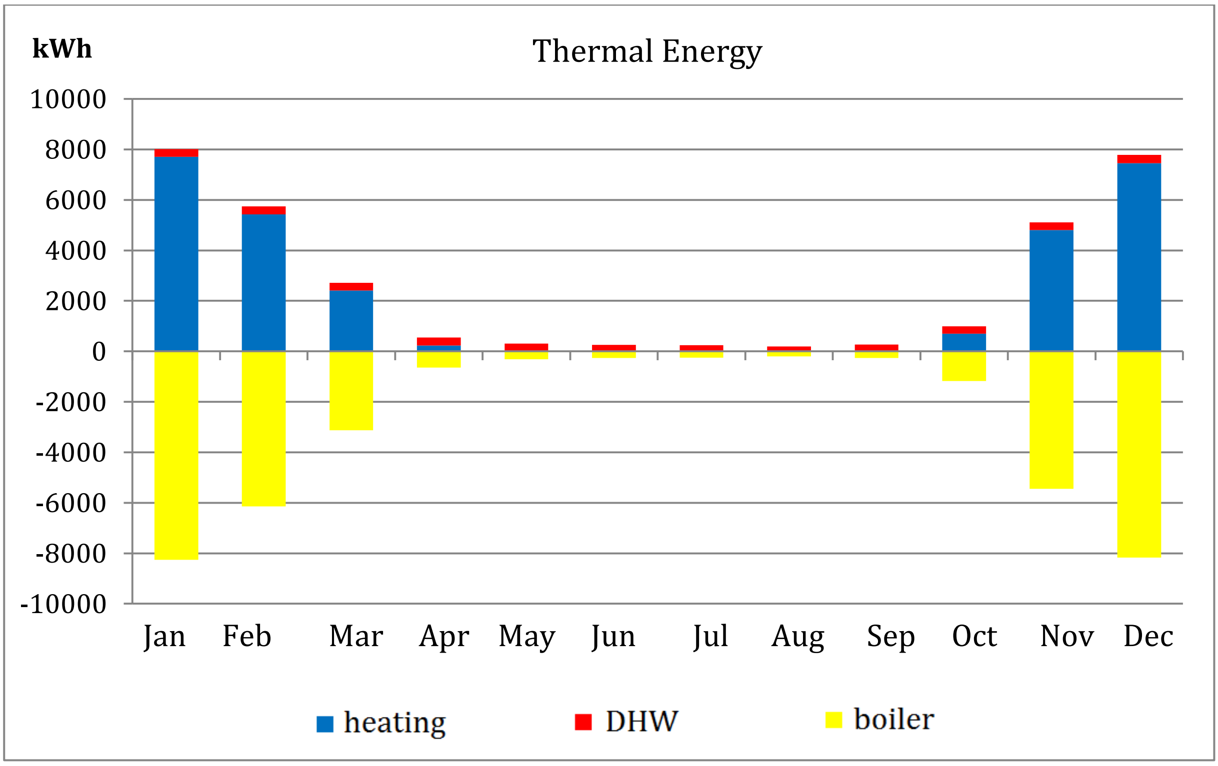


Figure 2.20. Energy needed and provided- CASE 0

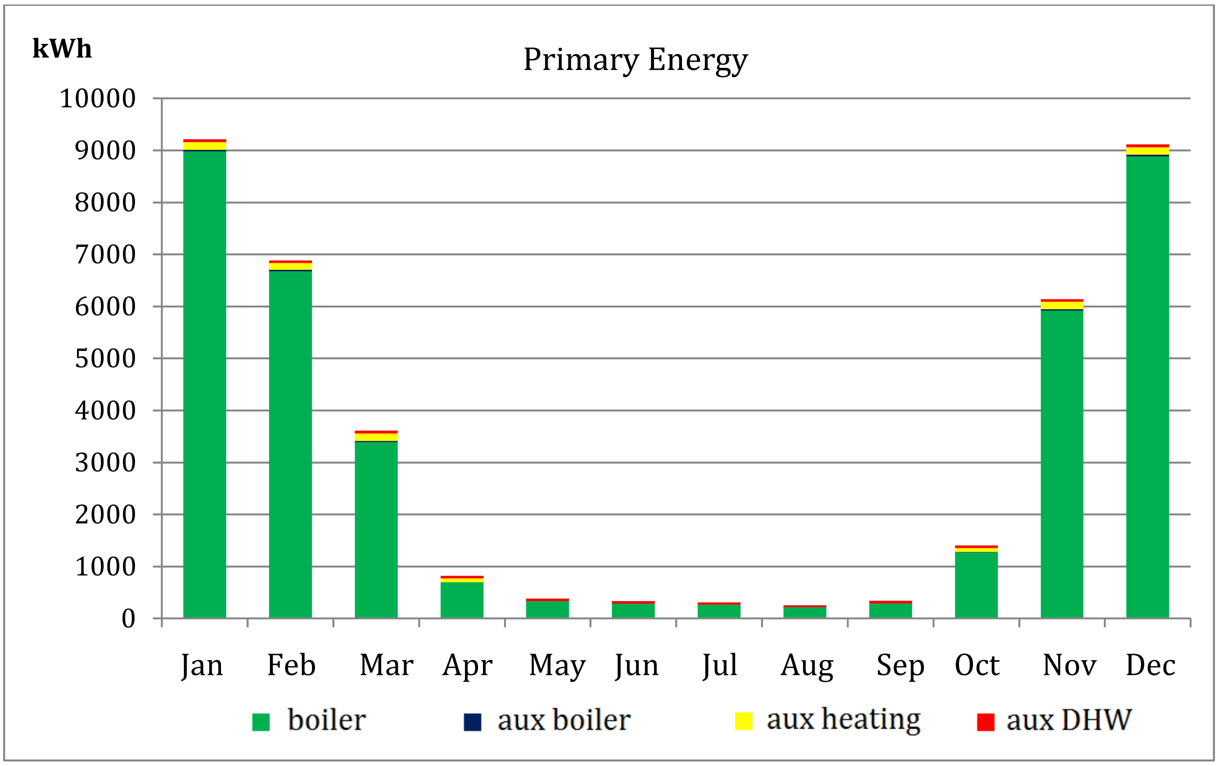


Figure 2.21. Primary energy demand - CASE 0

2.5.2 CASE A1

Before considering the interventions of external insulation and building retrofitting it is appropriate to examine how it is possible to achieve energy savings by implementing interventions with lower economic weight and minor modification interventions respect to the envelope and the system.
The simulation carried out with the label CASE A1 assumes, for example, to maintain both the conditions of the building both of the thermal plant. He difference respect to the former case study consist in a different management of the emission sub-system of the HVAC. Traditional radiators have been supply with low temperature water and they were run in continuous operation, so as to dampen the peak heating while ensuring the required energy. Setting a flow temperature for the radiators of 50 °C, made necessary to replace the traditional boiler with a condensing boiler, which allows a better operative behaviour.
Concerning the simulation, the worksheet, the logic with which the project was built, the analysis made and the measured items are the same as CASE 0, with the only exception of the data according to the control components of the flow temperature and the external file created to implement the condensing boiler.
The Table 2. 33 resumes the data and the parameter used in the simulation of the CASE A1. The results of the simulation carried out for the CASE A1 are resumed in the Table 2.34.
As it can be seen, the primary energy consumption decrease from 183.91 kWh/m^{2}year to 158.99 kWh/m^{2}year. Despite the dispersions through the envelope are increased, the peak of the heating is lower respect to the ante-operam situation, and equal to 13.4 kW. The energy required for heating remained almost identical but the energy that the boiler must supply decreases by about 10 kWh/m2. The electricity consumed by auxiliary circulators is pretty much the same as the previous case study.

Table 2. 33. Data and the parameter used in the simulation of the CASE A1.

SIMULATION DATA AND PARAMETER CASE A1: condensing boiler and radiators at low temperature		
BUILDING		
Transmittance coverage	W/m^2K	2.74
Transmittance of exterior walls	W/m^2K	1.41
Transmittance windows	W/m^2K	2.84
Infiltration	Vol/h	0.3
HVAC SYSTEM		
Traditional boiler		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Temperature set point	°C	60
Generation efficiency η_{gen}	-	1.003
VENTILATION		OFF (natural ventilation)
BOILER CONTROLLER		
Th (upper temperature input)	°C	60
UDB (upper dead band)	°C	6
LDB (lower dead band)	°C	2
SYSTEM TERMINALS		
Radiators		
Nominal flow	l/h	1500
Flow temperature	°C	50
GENRAL		
operation of the system		continuous
Ignition hours per day	h	24
Emission efficiency η_{em}	-	0.91
Regulation efficiency η_{reg}	-	0.93
Distribution efficiency η_{distr}	-	0.981

Table 2.34. Results of the simulation carried out for the CASE A1

CASE A1	**kWh**	**kWh/m²**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	26288	124.59
transmission	19214	91.06
ventilation	4564	21.63
Energy demand for heating (include the overall efficiency of the system)	28643	135.75
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	31785	150.64
Total energy supplied from the boiler to the tank	32064	151.96
Total demand of thermal energy	31968	151.51
Power absorbed by auxiliaries	728	3.45
circulation pump boiler	68	0.32
heating circulation pump	393	1.86
DHW circulation pump	267	1.27
Primary energy	33548	158.99

For a more detailed report the value recorded for the energy exchanged by the HVAC system and the users are presented in Figure 2.22 and Figure 2. 23, respectively in term of thermal and primary energy.

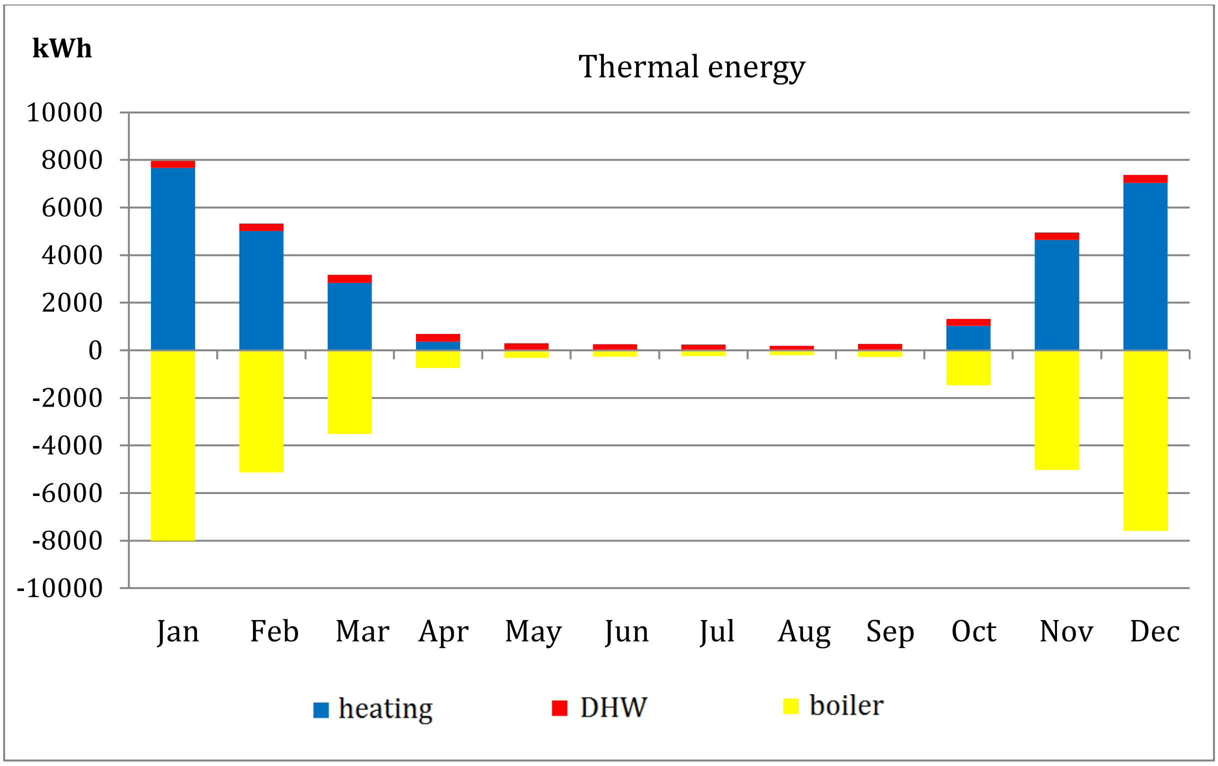


Figure 2.22. Energy needed and provided- CASE A1

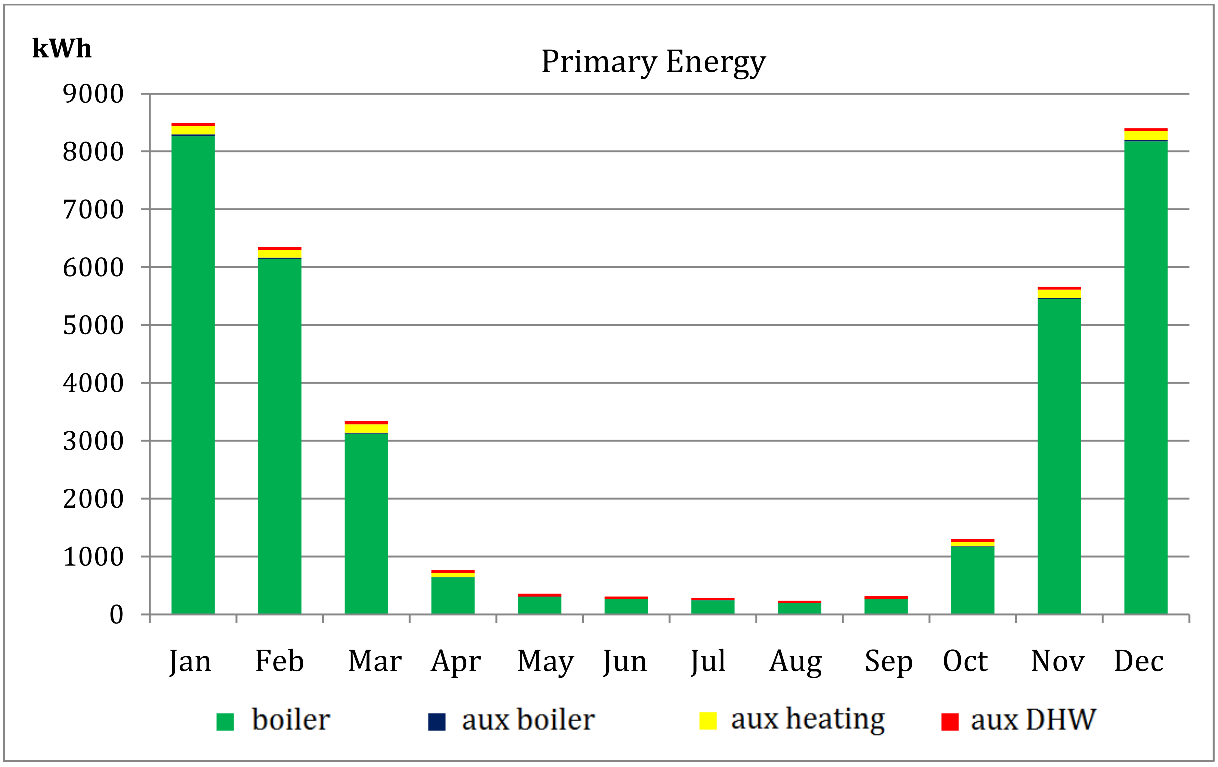


Figure 2. 23. Primary energy demand - CASE A1

2.5.3 CASE A2

The case study labeled as CASE A2 considers step forward respect to the previous analysis. While maintaining the condition of the building, the HVAC system was slightly modified by replacing the cast iron radiators with more efficient fan coils, managed to work at the lowest possible temperature level, with a flow temperature of 60 °C.

Concerning the simulation, the worksheet, the logic with which the project was built, the analysis made and the measured items are the same as CASE A1, with the only exception of the controller of the fun coils. delivered flow temperature. The Table 2.35 resumes the data and the parameter used in the simulation of the CASE A2. The results of the simulation carried out for the CASE A2 are resumed in the Table 2.36.

Table 2.35. Data and the parameter used in the simulation of the CASE A2.

SIMULATION DATA AND PARAMETERS CASE A2: condensing boiler and fun coils		
BUILDING		
Transmittance coverage	W/m^2K	2.74
Transmittance of exterior walls	W/m^2K	1.41
Transmittance windows	W/m^2K	2.84
Infiltration	Vol/h	0.3
HVAC SYSTEM		
Traditional boiler		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Temperature set point	°C	60
Generation efficiency η_{gen}	-	1.003
MCV		
Operation mode		OFF (natural ventilation)
BOILER CONTROLLER		
Th (upper temperature input)	°C	60
UDB (upper dead band)	°C	8
LDB (lower dead band)	°C	2
SYSTEM TERMINALS		
Radiators		
Nominal flow	l/h	3000
Flow temperature	°C	50
GENERAL		
operation of the system		intermittent
Ignition hours per day	h	14
Emission efficiency η_{em}	-	0.94
Regulation efficiency η_{reg}	-	0.93
Distribution efficiency η_{distr}	-	0.992

Table 2.36. Results of the simulation carried out for the CASE A2

CASE A2	**kWh**	**kWh/m^2**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	23778	112.69
transmission	19214	91.06
ventilation	4564	21.63
Energy demand for heating (include the overall efficiency of the system)	26468	125.44
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	29886	141.64
Total energy supplied from the boiler to the tank	30543	144.75
Total demand of thermal energy	30452	144.32
Power absorbed by auxiliaries	1601	7.59
circulation pump boiler	66	0.31
heating circulation pump	393	1.86
Fun coils ventilators	874	4.14
DHW circulation pump	267	1.27
Primary Energy	33926	160.79

For a more detailed report the value recorded for the energy exchanged by the HVAC system and the users are presented inFigure 2.24and Figure 2.25, respectively, in term of thermal and primary energy.

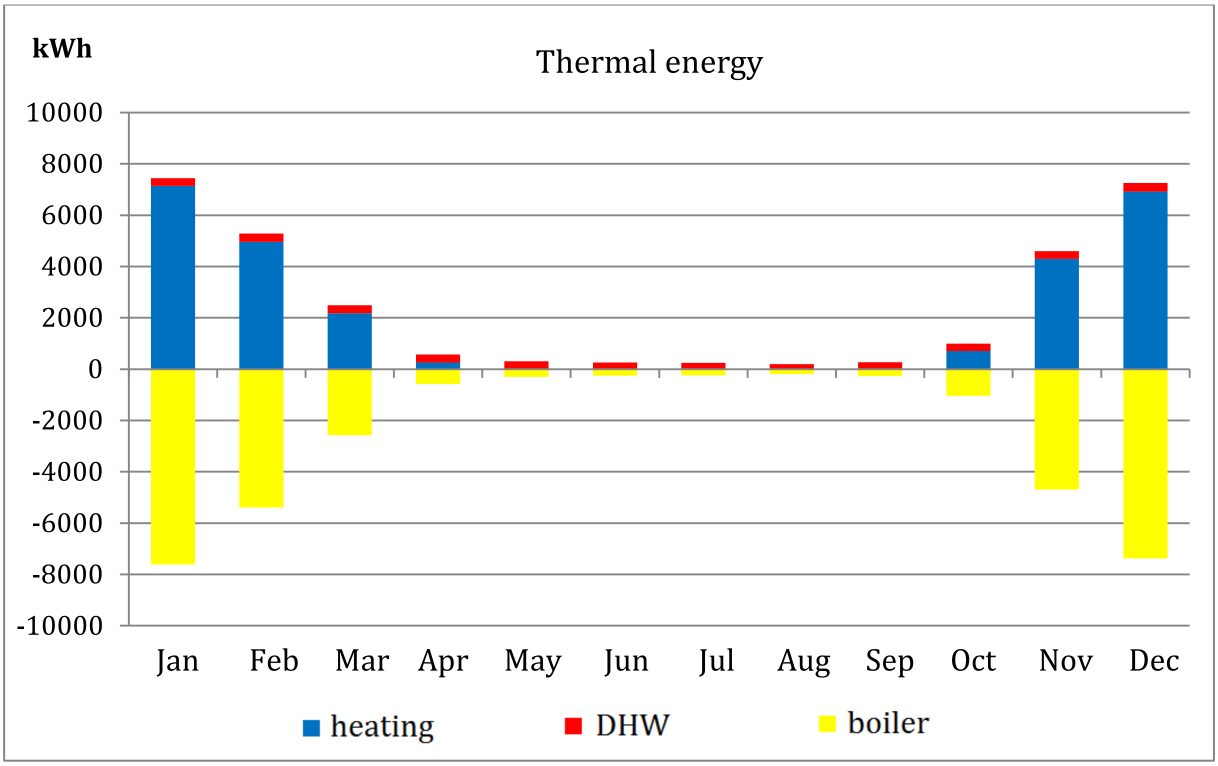


Figure 2.24. Energy needed and provided- CASE A2

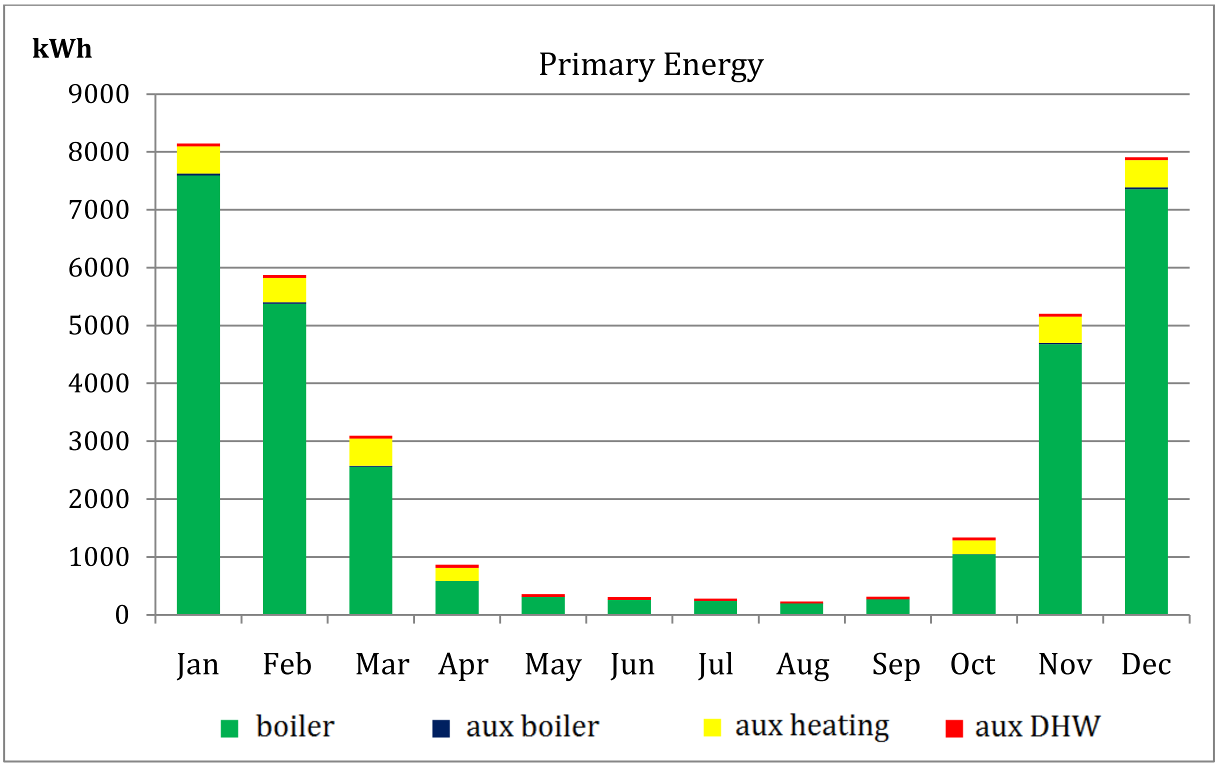


Figure 2.25. Primary energy demand - CASE A2

The analysis of the results obtained for the Case 0, A1 and A2 allows to derive some important considerations. The Table 2.37 presents a resuming of the major data to facilitate the comparison.

Table 2.37. Comparison among the results of the case studies 0, A1, A2

	CASE 0	CASE A1	CASE A2
Total Thermal Energy Demand [kWh/m^2]	176.31	151.51	144.32
Primary Energy Demand [kWh/m^2]	183.91	158.99	160.79

As can be seen, from the point of view of the overall requirements for thermal energy, replacement of radiators with fan coils favors the latter as it passes from 176.31 to 144.32 kWh/m^{2}year; the benefit is not so relevant if we compare this value with that obtained by working with low-temperature radiators, as the energy saving achieved in switching from a high to low temperature is greater than one saved with the use of fan coils instead of radiators managed with low temperature fluid.
Furthermore, comparing the primary energy consumption in cases A1 and A2 even a slight advantage in favor of the radiators has been found. In fact while being more expensive with regard to heat consumption, do not require the contribution of electricity needed by fan coils to operate the fans.
As a first analysis it can be argued that in the case study it is not worth either from an energy point of view, nor from an economic point of view, to replace the existing iron cast radiators with fan coils, it is rather more convenient to pass to a low temperature function for the existent emission devices.

2.5.4 Retrofit of the building

This chapter will present the actions evaluate for the retrofit of the building used in the simulations labeled as CASES B. There are four case study in this group. The retrofitting actions consist in the insulation of the building envelope and in the implementation of engineering solutions for the exploitation of renewable energy sources and the improve of the energy efficiency of the HVAC system.

According to the action evaluated on the envelope of the building, all the external surfaces have been equipped with different insulating solutions. Table 2.39 to Table 2.46 present the description of the surfaces used into the model of the retrofitted building. A comparison between the proposed stratigaphy and the ones presented in the paragraph 2.3.1 can be used to understand the entity of the implemented actions. The meaning of the symbols used in the tables are presented in Table 2.38.

Table 2.38. Legend for the description of the external structures of the envelope

QUANTITIES	SYMBOL	UNIT OF MEASURE
Size	D	[kg/m^3]
Density	s	[cm]
Thickness	λ	[W/m^{2}K]
Thermal conductivity of reference	λ_m	[W/m^{2}K]
Thermal conductivity calculated useful	m	[%]
Percentage increase	r	[m^{2}K /W]
Thermal resistance unified internal	CT	[kJ/kgK]

Table 2.39. External roof after retrofit physical and thermal properties

S1- EXTERNAL ROOF							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.100	
Roof structure 2.1.02i 60	617	6			0.428	0.140	0.92
Standard concrete	2200	4	1.28	0	1.28	0.031	0.88
Isulation Stirodur 2800CS-40mm	**35**	**4**	**0.032**		**0.032**	**1.250**	**0.85**
Bitumen	1200	0.4	0.17	0	0.17	0.024	0.92
Liminal outer layer						0.100	
TOTAL		10.4				0.365	
U-value [W/(m^{2}K)]				0.608			

Table 2.40. External wall after retrofit physical and thermal properties

S2- EXTERNAL WALL							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Lime cement sand mortar	1800	2.5	0.9	0	0.9	0.028	0.91
Perforated brick 1.1.04 (b) 250	1188	25			0.533	0.469	0.92
Lime mortar or lime concrete	1800	2.5	0.9	0	0.9	0.028	0.91
Adhesive coat	1650	0.5	0.51		0.51	3.000	0.86
EPS040 Expanded Polystyrene	30	12	0.04		0.04	0.010	1.25
Cement smoother	1650	0.5	0.51	0	0.51	0.010	0.86
Plaster in paste	1800	0.3	0.7	0	0.7	0.004	1
Liminal outer layer						0.040	
TOTAL		30.8				0.709	
U-value [W/(m^{2}K)]	0.269						

Table 2.41. Inter-floor after retrofit physical and thermal properties

S3- INTER-FLOOR							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.5	1	0	1	0.015	0.84
Screed additive for radiant panel	2000	1.5	1		1.2	0.054	1.25
040 EPS - Expanded Polystyrene	30	6.5	1.2		0.04	0.750	0.92
concrete with polystyrene	500	10	0.15	0	0.15	0.667	0.92
Lime mortar or lime concrete	1800	2	0.9	0	0.9	0.022	0.91
Block attic 2.1.031 / 1	950	18			0.599	0.300	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Outer layer of liminal						0.170	
TOTAL		32.5				1.185	
U-value [W/(m^{2}K)]	0.463						

Table 2.42. Structural partition after retrofit physical and thermal properties

S4- STRUCTURAL PARTITION							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Plasterboard	750	2.5	0.6	0	0.6	0.042	0.84
Perforated brick 1.1.04 (b) 250	1188	25			0.533	0.469	0.92
Lime mortar or lime concrete	1800	2.5	0.9	0	0.9	0.028	0.91
Liminal outer layer						0.130	
TOTAL		30				0.799	
U-value [W/(m^{2}K)]	1.252						

Table 2.43. *i*nternal wall after retrofit physical and thermal properties

S5- INTERNAL WALL 10							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.130	
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Hollow brick 1.1 19 80	775	8			0.4	0.200	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Liminal outer layer						0.130	
TOTAL		10				0.482	
U-value [W/(m^{2}K)]	2.074						

Table 2.44. Outdoor floor after retrofit physical and thermal properties

S6- OUTDOOR FLOOR							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.5	1	0	1	0.015	0.84
Concrete with polystyrene	500	8	0.15	0	0.15	0.533	0.92
Lime mortar or lime concrete	1800	2	0.9	0	0.9	0.022	0.91
Block slab 2.1.031 / 1	950	18			0.599	0.300	0.92
Adhesive coat	1650	0.5	0.51		0.51	1.250	0.86
EPS. block UNI 7819 25	25	5	0.04		0.04	0.010	1.25
Cement smoother	1650	0.5	0.51	0	0.51	0.010	0.86
Plaster in paste	1800	0.3	0.7	0	0.7	0.004	1
Liminal outer layer						0.040	
TOTAL		30.3				1.055	
U-value [W/(m^{2}K)]	0.247						

Table 2.45. Basement after retrofit physical and thermal properties

S7- BASEMENT							
Description	D	s	λ	m	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Ceramic tiles	2300	1.3	1	0	1	0.013	0.84
Ordinary concrete	2200	5	1.28	0	1.28	0.039	0.88
Polyethylene (PE)	950	0.1	0.35		0.35	1.250	1.25
EPS040 - Expanded Polystyrene	30	5	0.04		0.04	0.667	0.92
Concretewith polystyrene	500	10	0.15	0	0.15	0.667	0.92
Extruded Polystyrene Foam	50	5	0.032	0	0.032	1.562	1.25
Pebbles and crushed stones	1500	8.6	0.7	0	0.7	0.123	0.84
Liminal outer layer						0.040	
TOTAL		29.9				2.577	
U-value [W/(m^{2}K)]	0.256						

Table 2.46. Floor attic after retrofit physical and thermal properties

S8- FLOOR ATTIC							
Description	D	S	λ	M	λ_m	r	CT
Indoor air							
Liminal inner layer						0.170	
Rock Wool	**22**	**16**	**0.042**		**0.042**	**3.810**	**1.03**
Sheath vapor barrier	133	0.1			0.4	0.002	0.84
Ordinary concrete	2200	2	1.28	0	1.28	0.016	0.88
Block slab 2.1.031 / 1	950	18			0.599	0.300	0.92
Lime mortar or lime concrete	1800	1	0.9	0	0.9	0.011	0.91
Liminal outer layer						0.170	
TOTAL		21.1				0.500	
U-value [W/(m^{2}K)]	0.223						

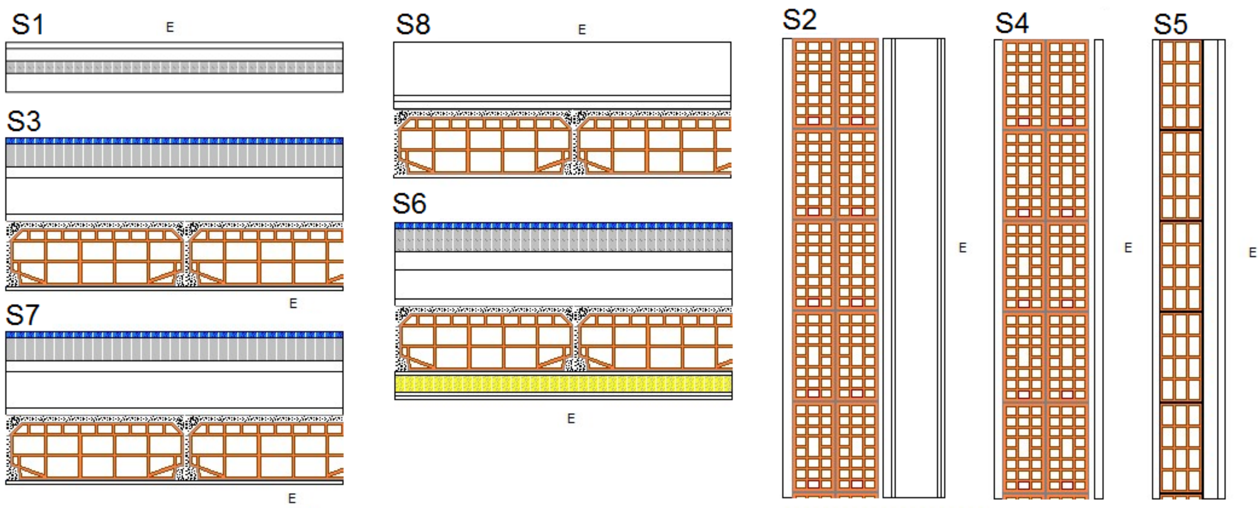


Figure 2.26. Section of the structures used to model the building envelope.

2.5.5 CASE B1

In addition to the replacement of traditional gas boilers with condensing ones, already assumed in the case studies belonging to group A, the group of simulation labeled as Cases B introduce some actions affected also the HVAC system. In the Case B1 a solar thermal system is added to the plant, in order to contribute at the heat generation necessary to satisfy the domestic hot water demand. The purpose is to limit as much as possible the ignition of the heat generator and drastically reduce the consumption of primary energy. To store the thermal energy provided by the solar collectors a thermal storage tank is necessary. The storage allows to eliminate the daily phase shift between the request of energy by the user and the availability of the solar collector energy supply, the latter being dependent on the instantaneous incident solar radiation.

In the CASE A1 radiators operating with low temperature fluid are assumed as heat emission devices, because of the great degree of thermal insulation of the outer walls. The model also incorporates a controlled mechanical ventilation system.

In the worksheet, in addition to the circuits present in the previous simulations, can be noticed:

- Circuit of the solar system (orange): flat plate solar collectors, pump, regulator
- Thermal storage tank
- External files: climate data necessary to evaluate the solar irradiations on the collectors
- Calculator for calculating the energy supplied by the solar collectors

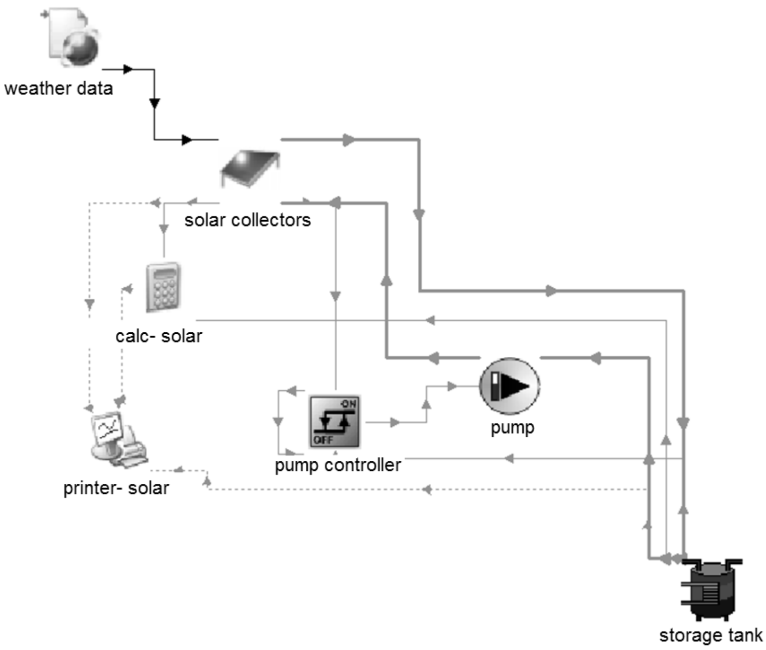


Figure 2.27. Model description - solar system circuit

The project maintains the same logic described for the previous case studies. the addition consists in the circuit of the solar system collector and in the devices necessary for its operation. The flow of the information through the types starts with the solar collectors, which receive information about the outdoor climate by the means of the external weather data reader , which is provided with the climate data of the test reference year (TRY)of Venice. The solar collectors are connected to the thermal storage and the flow of the operative fluid is guarantee by the means of the solar pump. The heat collected by the solar system is delivered to the water in the tank through a coiled heat exchanger, placed in the bottom part of the storage. The hot eater coming from the collectors, circulates into the heat exchanger , and due to the favorable gradient temperature release heat to the fluid in the tank contributing to the HDW generation. The flow at the outlet of the tank, has a lower temperature due to the released heat, it is delivered to the solar collector by the solar pump in a cyclic operation. The pump is managed by an on/off controller , which monitors the temperature difference between the operative fluid at the outlet of collectors and the temperature of the fluid inside the tank closet to the heat exchanger. When the temperature difference in positive, and satisfy the minimum value set by the operator, the pump is turned on, on the contrary if the difference is negative or too low, the pump is turned off.

The parameters required for the simulation of the solar collectors are:

- Total net surface of the solar field [m^2]
- Number of collectors in series [-]
- Specific heat capacity of the operative fluid [k /kgK]
- Nominal flow rate [kg/h]
- Maximum tested specific flow [kg/hm^2]
- Optical efficiency [-]
- Linear coefficient for the collectors performance index, a_1 [kJ/hm^2K]
- Quadratic coefficient for the collectors performance index, a_2 [kJ/hm^2K^2]

The parameters required for the simulation of the thermal storage tank are:

- Tank volume [m^3]
- Height of tank [m]
- Thermal loss coefficient at the top, bottom and at the edge of the tank [$kJ / h\ m^2K$]
- Number of nodes in which the tank volume is divided for the purpose of the simulation
- Number of inlet/outlet of the tank
- Number of heat exchangers immersed and their geometrical and physical characteristics

According to the implementation of the storage tank, it has been very complex and some difficulties had to be overcome in order to achieve a satisfying model for the component. The tank had to be modeled been very carefully in the positioning of the inlet and the outlet of the tank, as well as the position of the heat exchanger and the definition of its geometrical features. Often the technical information provided by the producers of several thermal storage tank are not enough detailed in order to implement a model as the one used in this simulation. In the case study, the storage has been chosen in order to allow a complete implementation of its features to guarantee a proper model definition.

The tank modeled in this case presents three ports (a port is an inlet/outlet couple) connected to as many circuit of the system, and one immersed heat exchanger, connected to the solar collectors. The volume of the tank has been divided into nine elements, labeled as node. This element of volume are the basis for the calculation of the energy an mass balance of the tank. A description of the connection of the storage with the rest of the system is provided below:

- PORT 1: communication with the circuit of the boiler; 4 IN 2 OUT
- PORT 2: communication with the heating circuit; 7 IN OUT 3
- PORT 3: communication with DHW circuit; 1 IN 8 OUT
- EXCHANGER 1: communication with the solar circuit; OUT IN 6 9

The presented configuration of the thermal storage has been chosen in order to achieve the best possible performance due to the inner fluid stratification. In fact it is well known that realize a good separation among the temperature levels of the tank volume allows a better utilization of its thermal capacity. To maintain this favorable conditions the flow rates along the ports should have low values, and the connection between the tank and the circuits of the system should be placed in order to mutually meet its temperature levels. Obviously these conditions cannot be always satisfy, so the difficult part of the storage modeling is find the better configuration according to the variable operative conditions.

The second major innovation introduced with the CASE B1 consist in the modelization of the MCV system. The mechanical ventilation has been implemented by the means of an interaction between TRNSYS and EXCEL. The input values necessary for the analysis are:

- Outside temperature [° C]
- Outdoor relative humidity [%]
- Internal temperature [° C]
- Indoor Relative Humidity [%]
- External atmospheric pressure [bar]
- Internal pressure [bar]
- On / off control [-]

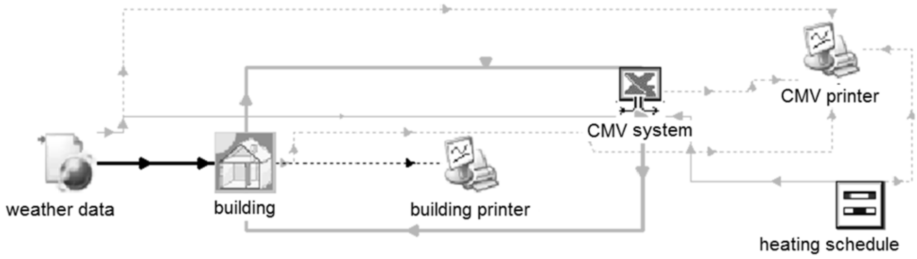
and the program provide as output:

- Air flow rate [kg/h]
- Air flow temperature [°C]
- Relative humidity [%]
- Sensible heat exchanged with the air flow [kWh]
- latent heat exchanged with the air flow [kWh]

The excel worksheet contains the properties of the moist air and it is structured so as to calculate the characteristics of the operation of the MCV systems in terms of flow rate, temperature and humidity; all taking into account the presence of a heat exchanger static cross-flow which is can set the degree of efficiency.
Taking into account the geometrical characteristics of the building and job profiles it was decided to set two values for the air flow rate:

0.56 Vol/h	during the hours of presence of people
0.1 Vol/h	during the hours without presence of people

The first value, related to the presence of people, has been chosen according to the Italian standard UNI 15251 2008 – "Classi di Ventilazione Meccanica"[16]. This is the value suggested by the standard for a CMV systems of middle quality class (class B) among a three level classification scale proposed. The second value has been calculated according to the Italian UNI 15251, in which where there is no presence of people in the building is recommended an air change between 0.05 e 1.0 l/sm^2 . in the analysis an average value of 0.075 l/sm^2 has been used, and, evaluating in 120 m^2 the area affected by the action of the mechanical ventilation system, an air change rate equal to 0.1 Vol/h have been imposed.



The performances of the MCV system have been evaluated according to three different values of the efficiency of the heat recovery. The share between the energy demand related to sensible and latent heat has been evaluated, as well as the auxiliary energy demand to operate the fan. All the terms are taking into account in the calculation of the global primary energy related to the ventilation system. The results of the analysis are presented in
Table 2.47. The Table 2. 48 and the Table 2.49the resume the data and the parameter used in the simulation of the CASE B1, and the results of the analysis.

Table 2.47. Performances of the MCV system according to the heat recovery efficiency

Heat recovery efficiency	**0.5**		**0.7**		**0.9**	
	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
Sensible heat	1734	8.22	1196	5.67	722	3.42
Latent heat	386	1.83	382	1.81	0	0
Total energy	2120	10.05	1578	7.48	722	3.42
Fan electrical energy	876	4.15	799	3.785	679	3.22
Fan primary energy	1901	9.01	1732	8.21	1473	6.98
Total primary Energy	4022	19.06	3311	15.69	2194	10.40

Table 2. 48. Data and the parameter used in the simulation of the CASE B1.

SIMULATION DATA AND PARAMETERS CASE B1:condensing boiler , radiators, solar collectors, CMV system		
BUILDING		
Transmittance coverage	W/m^{2}K	0.608
Transmittance of exterior walls	W/m^{2}K	0.269
Transmittance windows	W/m^{2}K	1.137
Air leakages	Vol/h	0.1
HVAC SYSTEM CONDENSING BOILER		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Set point temperature	°C	60
Generation efficiency η_{gen}	-	1.003
SOLAR COLLECTORS		
Aperture net area	m^2	6.9
Operative fluid specific heat	kJ/kgK	4.190
Design flow rate	kg/h	100
MCV		
Daily hour of operation	h	24 (2 flow rate values)

Max air change rate (17h)	Vol/h	0.56
Min air change rate	Vol/h	0.1
BOILER CONTROLLER		
Th (upper input temperature)	°C	60
UDB (upper dead band)	°C	5
LDB (lower dead band)	°C	2
EMISSION SUB-SYSTEM - Radian floor system		
Design flow rate	kg/h	1500
Set point temperature	°C	50
Operation mode		Continuous
GENERAL		
Daily hour of operation	h	24
Emission efficiency η_{em}	-	0.92
Regulation efficiency η_{reg}	-	0.93
Delivery efficiency η_{distr}	-	0.9915

Table 2.49. Results of the simulation carried out for the CASE B1

CASE B1	**kWh**	**kWh/m²**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	3649	17.29
transmission	3274	15.51
infiltration	375	1.78
Ventilation	2120	10.05
Energy demand for heating (include the overall efficiency of the system)	5007	23.73
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	8425	39.93
Total energy supplied by the boiler to the tank	6781	32.14
Total energy supplied by the solar collector to the tank	2025	9.60
Power absorbed by auxiliaries	1257	5.95
circulation pump boiler	9	0.04
heating circulation pump	219	1.04
DHW circulation pump	267	1.27
solar system pump	130	0.62
MCV fans	632	3.0
Primary energy	9488	44.97

The difference between the total energy demand recorded at the tank and the total energy supply to this component depends, minus the thermal losses, to the regulation efficiency of the system. In fact all the other efficiency terms have been taking into account at different stages of the energy demand evaluation procedure, but this item is related to the logics of control of the HVAC system. The simulation assets a regulation efficiency equal to 0.95. The simulation results show that the dispersions of the building undergo to a drastic reduction , decreasing from 122.69 kWh/m^2 in the ante-opera scenario to the 17.29 kWh/m^2 of the case into consideration. This result has been achieved through a high degree of the building insulation. To the heat dispersion through the envelope must be added the dispersions due to the air flow changing operated by the means of the CMV system, for a global value of thermal losses equal to 27.34 kWh/m^2. The overall value results to be 4 times lower respect to the CASE 0. While the energy demand to DHW generation, its value remains unchanged (16:20 kWh/m^2),

the energy required for heating decrease from 136.27 to 23.73 kWh/m^2. The electricity consumption, on the contrary, increases but is due mainly to the presence of the fans of the ventilation system .
The primary energy is also reduced by approximately 4 times compared to the initial situation , thanks to the excellent degree of isolation and achieved and the contribution of the solar collectors, which contribute to cover 24% of the total required thermal energy.

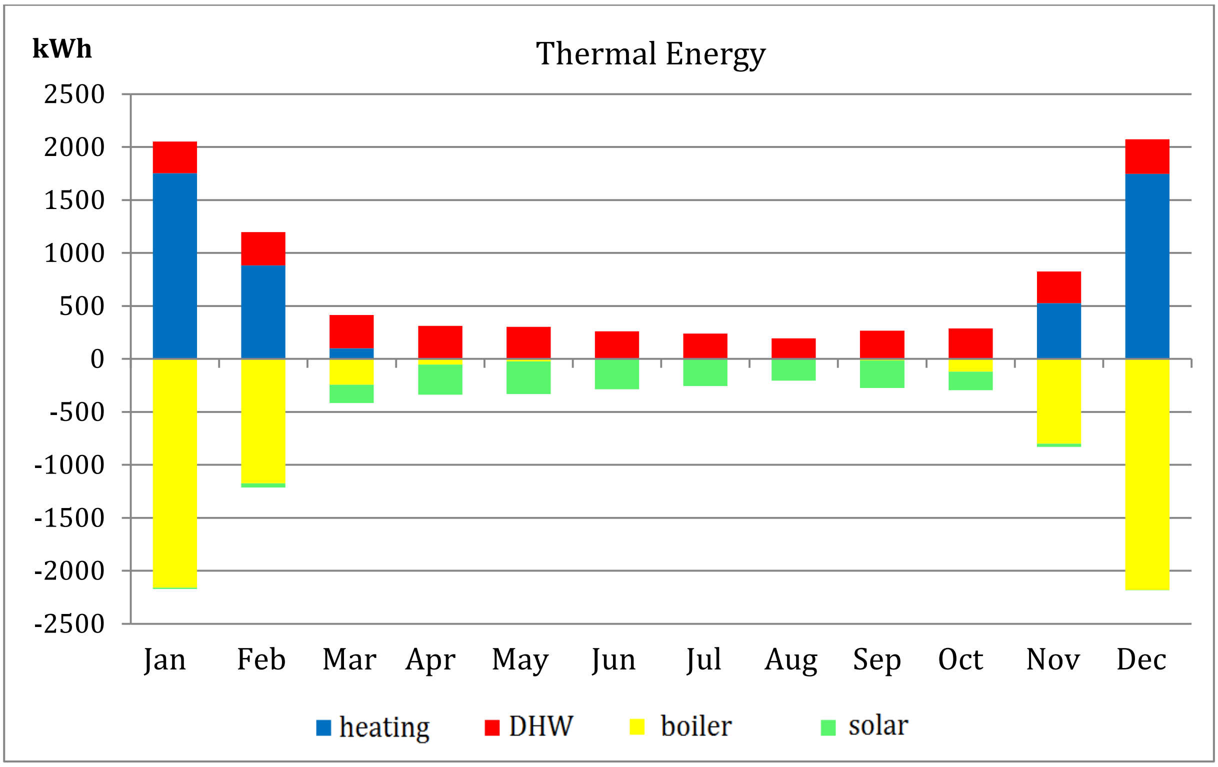


Figure 2. 28. Energy needed and provided- CASE B1

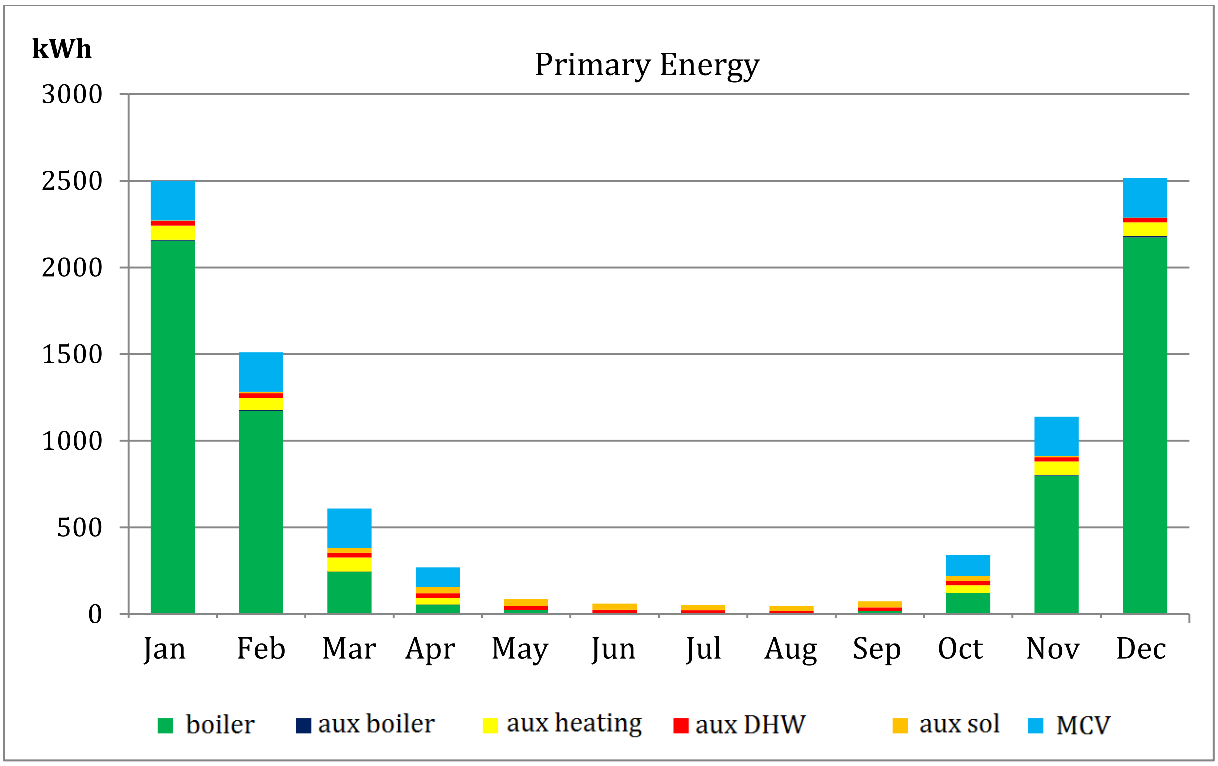


Figure 2. 29. Primary energy demand - CASE B1

2.5.6 CASE B2

The CASE B2 considers the replacing the radiators with a radiant floor system combined as in the previous case to condensing boiler and solar thermal collectors. The major advantage in using radiant panels is the low difference temperature between the operative flow and the indoor environment, in fact the available large exchange surface allows to transfer the heat required maintaining a lower delivery temperature respect to radiators or fan coils. Furthermore, the flow temperature reaches very low values due to the climatic control, i.e. the water delivery temperature is function of the outdoor temperature, and the low return temperatures favor the condensation of water , enhancing the operation performance of the condensing boiler.

The Figure 2.30 proposes a draft of the system according the heating circuit, the radiant panels circuit is highlighted, whose return temperature is evaluated by the calculator according to the design flow rate, the delivery temperature and the energy need of the building. The climatic controller receives the external temperature value from the weather data file and pilots the thermostatic valve to supply the radiant floor system, the flow temperature is set by the Equation (3), represented also in Figure 2.30.

$$T_{delivery} = -0.8\,(T_{outdoor}) + 34 \;\; [°C] \qquad (3)$$

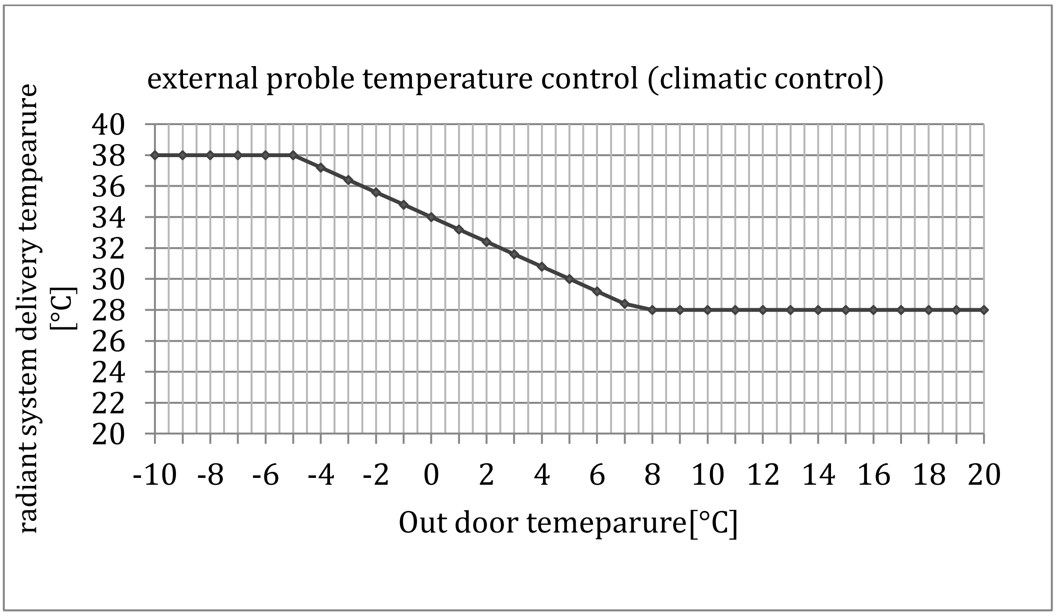


Figure 2.30. Mathematical relation used within the external probe control

The Table 2.50 resumes the data and the parameter used in the simulation of the CASE B2, while the results of the simulation are presented in Table 2.51.

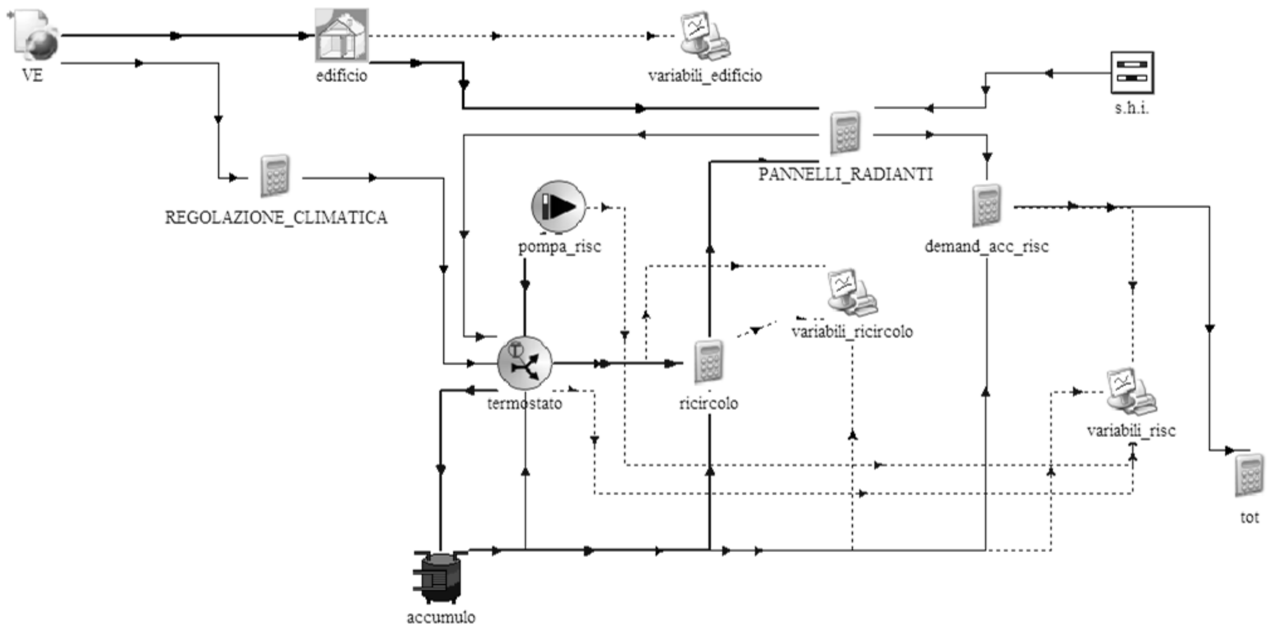


Figure 2. 31. Model description - heating circuits

Table 2.50. Data and the parameter used in the simulation of the CASE B2.

SIMULATION DATA AND PARAMETERS CASE B2:condensing boiler , radiant floor system, solar collectors, CMV system		
BUILDING		
Transmittance coverage	W/m^2K	0.608
Transmittance of exterior walls	W/m^2K	0.269
Transmittance windows	W/m^2K	1.137
Air leakages	Vol/h	0.1
HVAC SYSTEM CONDENSING BOILER		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Set point temperature	°C	60
Generation efficiency η_{gen}	-	1.003
SOLAR COLLECTORS		
Aperture net area	m^2	6.9
Operative fluid specific heat	kJ/kgK	4.190
Design flow rate	kg/h	100
MCV		
Daily hour of operation	h	24 (2 flow rate values)
Max air change rate (17h)	Vol/h	0.56
Min air change rate	Vol/h	0.1
CONTROLLER		
Th (upper input temperature)	°C	60
UDB (upper dead band)	°C	5
LDB (lower dead band)	°C	2
EMISSION SUB-SYSTEM - Radian floor system		
Design flow rate	kg/h	1500
Set point temperature	°C	Climatic control

GENERAL		
Operation mode		continuous
Daily hour of operation	h	24
Emission efficiency η_{em}	-	0.99
Regulation efficiency η_{reg}	-	0.94
Delivery efficiency η_{distr}	-	0.9975

Table 2.51. Results of the simulation carried out for the CASE B2

CASE B2	**kWh**	**kWh/m^2**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	3819	18.10
transmission	3274	15.51
infiltration	375	1.78
Ventilation	2120	10.05
Energy demand for heating (include the overall efficiency of the system)	4123	19.54
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	7542	35.75
Total energy supplied from the boiler to the tank	5545	26.28
Total energy supplied by the solar collector to the tank	2140	10.14
Power absorbed by auxiliaries	1268	6.01
circulation pump boiler	6	0.03
heating circulation pump	219	1.04
DHW circulation pump	267	1.27
solar system pump	144	0.68
MCV fans	632	3.0
Primary Energy	7991	37.87

The installation of radiant floor panels brings the following improvements compared to the case B1 where the plant was equipped with low temperature radiators:

- 17.6%of reduction of the energy required for heating
- 18.2% of reduction of the energy supplied by the boiler
- 15.8%of reduction of primary energy consumption

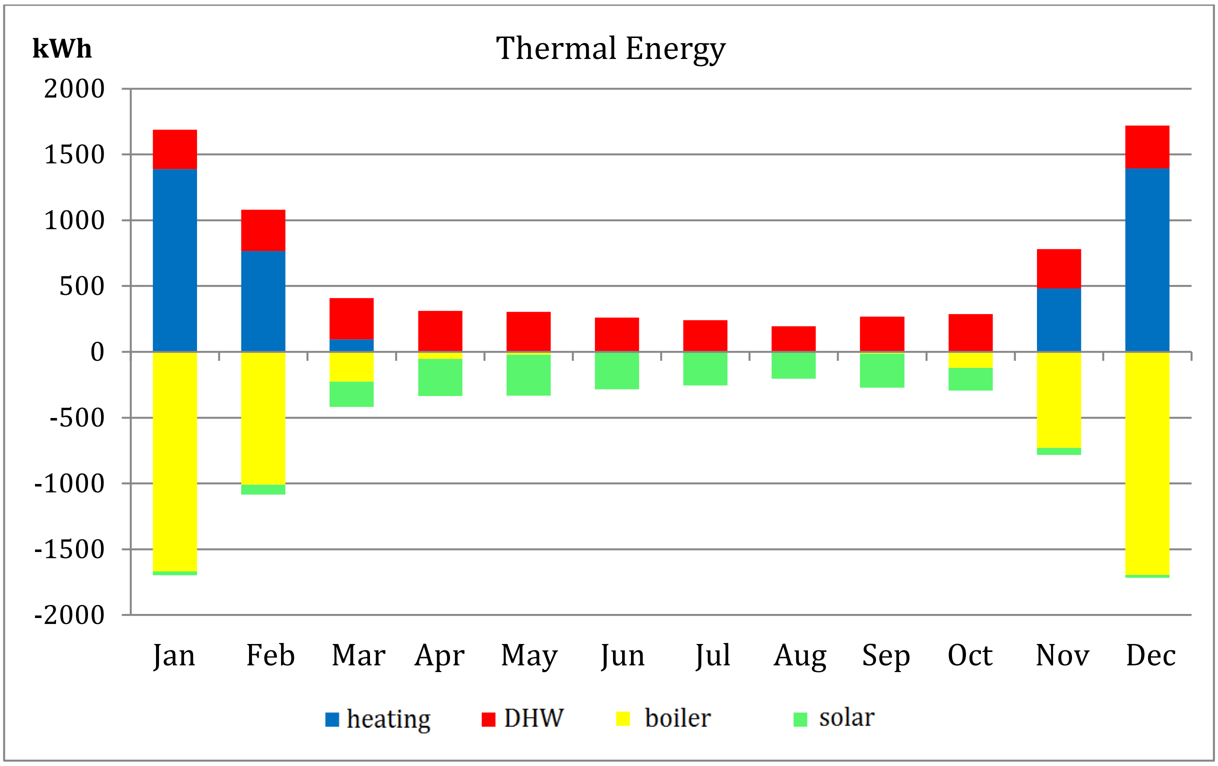


Figure 2. 32. Energy needed and provided- CASE B2

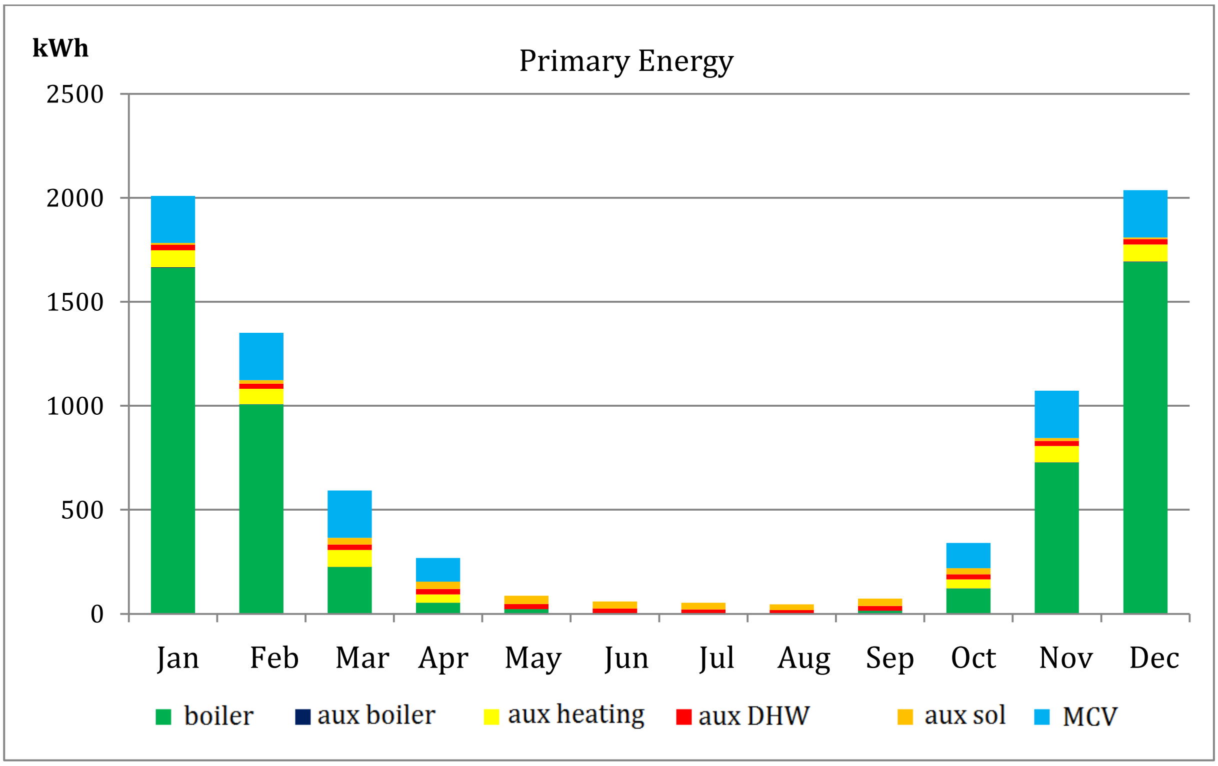


Figure 2. 33. Primary energy demand - CASE B2

2.5.7 CASE B3

The case study identify as CASE B3 in addition to the system configuration previously analyzed considers a further het generation system, integrated to the gas condensing boiler and the solar collectors system. The introduced device is an air-water heat pump, managed to operate with a low temperature range in order to better match the needs of the radiant floor panels used for space heating. The purpose is to provide the heating system with the energy delivered by the heat pump as much as the operative conditions allowed it, leaving to the solar collectors and the condensing boiler the task of meeting the demand for domestic hot water. The boiler however is called to integrate the heat pump when the energy provided is lover respect to the heat load, due to outdoor climate conditions (low temperature, high humidity) or to an increase in the thermal energy demand.
In the model of the HVAC system, the operation of the heat pump has been simulated using an Excel spreadsheet: The file processes the following input data:

- Outdoor air temperature [°C]
- Outdoor relative humidity [%]
- Outdoor asbsolute humidity [kg_v/kga_s]
- Water inlet temperature [°C]
- Set point temperature [°C]
- Control signal on/off [-]

and returns the following output values:

- Outlet water temperature [°C]
- Water flow rate [kg/h]
- Condensing power [kW]
- Electrical power consumption and auxiliary power [kW]
- COP [-]
- Evaporating temperature [°C]
- Condensing temperature [°C]
- Frequency [Hz]

The logic within the spreadsheet is very articulate and considers the interaction between the different components that characterize the operating cycle, i.e. the compressor, evaporator and condenser plate heat exchanger. The machine implemented is a reversible reversible heat pump and the powers of the evaporator and the condenser are calculated through a continuous series of interpolations of the power-frequency curves.
The models, in winter conditions, takes into account the negative effect due to the temporary formation of frost on the evaporator, especially in the case of particularly harsh external conditions. This deterioration in the performance of the heat pump is evaluated a decrease in terms of the Coefficient of Performance of the machine (COP) and of the heating capacity; the penalization could be estimated in 10 percentage points. The ignition of the heat pump is bounded to a minimum value of the COP equal to 2.17, in order to guarantee the employ of the most efficient component between the boiler and the heat pump, according to the effective operative conditions.
The Figure 2.34 shows the draft of the heat pump circuit.

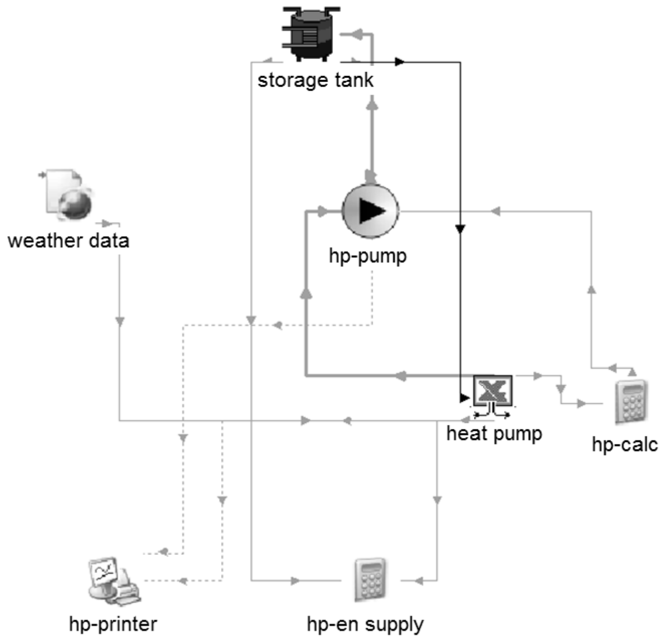


Figure 2.34. Model description - heat pump circuit

In the worksheet of the TRNSYS simulation Studio the components for the heat pump circuits are:

- excel spreadsheet of the heat pump
- thermal storage
- circulation pump
- weather data file
- calculator to evaluate hp power output
- printer to graphically display the input-output data

The HP introduced in the model need to be connected to the thermal storage. The connections between the tank and the HVAC system circuits need to be reconfigured. The new structure of the ports and the heat exchanger position inside the tank changes is:

- PORT 1: connection with the boiler circuit; 2 IN - 1 OUT
- PORT 2: connection with the heating circuit, 1 IN - 8 OUT
- PORT 3: connection with the heat pump circuit; OUT 4 - IN 7
- EXCHANGER 1: connection with the solar circuit; OUT 6 - IN 9
- EXCHANGER 2: connection with the DHW circuit; OUT 9 - IN 1

The chosen setting for the connections between the HVAC circuits and the thermal storage was optimized in order to guarantee the optimum match among the temperatures of the involved flow and of the inner volume, to favor the heat stratification inside the tank. So the delivery connection to the boiler has been placed in the higher nodes of the tank, as well as the feeding of the DHW delivery circuit. On the contrary, the heat exchanger of the solar circuit has been placed in the lower part of the storage, so ,that in favorable conditions, it can raise the temperature of the entire inner volume. The heat pump is also positioned in the lower middle part of the storage as low temperature operation is dedicated to power the radiant floor system.

The Table 2.52 resumes the data and the parameter used in the simulation of the CASE B3, while the results of the simulation are presented in Table 2.53.

Table 2.52. Data and the parameter used in the simulation of the CASE B3.

SIMULATION DATA AND PARAMETERS CASE B3:condensing boiler ,heat pump, radiant floor system, solar collectors, CMV system		
BUILDING		
Transmittance coverage	W/m^2K	0.608
Transmittance of exterior walls	W/m^2K	0.269
Transmittance windows	W/m^2K	1.137
Air leakages	Vol/h	0.1
HVAC SYSTEM CONDENSING BOILER		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Set point temperature	°C	60
Generation efficiency η_{gen}	-	1.003
Generation efficiency η_{gen}	-	1.003
SOLAR COLLECTORS		
Aperture net area	m^2	6.9
Operative fluid specific heat	kJ/kgK	4.190
Design flow rate	kg/h	100
HEAT PUMP		
Power rating	kW	8.0
Design flow rate	kg/h	1800
Set point temperature	°C	Climatic control
MCV		
Daily hour of operation	h	24 (2 flow rate values)
Max air change rate (17h)	Vol/h	0.56
Min air change rate	Vol/h	0.1
CONTROLLER		
Th (upper input temperature)	°C	60
UDB (upper dead band)	°C	5
LDB (lower dead band)	°C	2
EMISSION SUB-SYSTEM - Radian floor system		
Design flow rate	kg/h	1500
Set point temperature	°C	Climatic control
GENERAL		
Operation mode		continuous
Daily hour of operation	h	24
Emission efficiency η_{em}	-	0.99
Regulation efficiency η_{reg}	-	0.94
Delivery efficiency η_{distr}	-	0.9975

Table 2.53. Results of the simulation carried out for the CASE B3

CASO B3	**kWh**	**kWh/m^2**
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	3649	17.29
transmission	3274	15.51
infiltration	375	1.78
Ventilation	2120	10.05
Energy demand for heating (include the overall efficiency of the system)	4046	19.18
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	7457	35.38
Total energy supplied by the boiler to the tank	4445	21.07
Total energy supplied by solar collectors to the tank	1939	9.19
Total energy supplied by the heat pump to the tank	1537	7.28
Power absorbed by auxiliaries	1769	8.38
circulation pump boiler	6	0.03
heating circulation pump	219	1.04
DHW circulation pump	267	1.27
solar system pump	144	0.68
MCV fans	632	3.0
Compressor and circulators of the HP	501	2.37
Primary Energy	6832	32.38

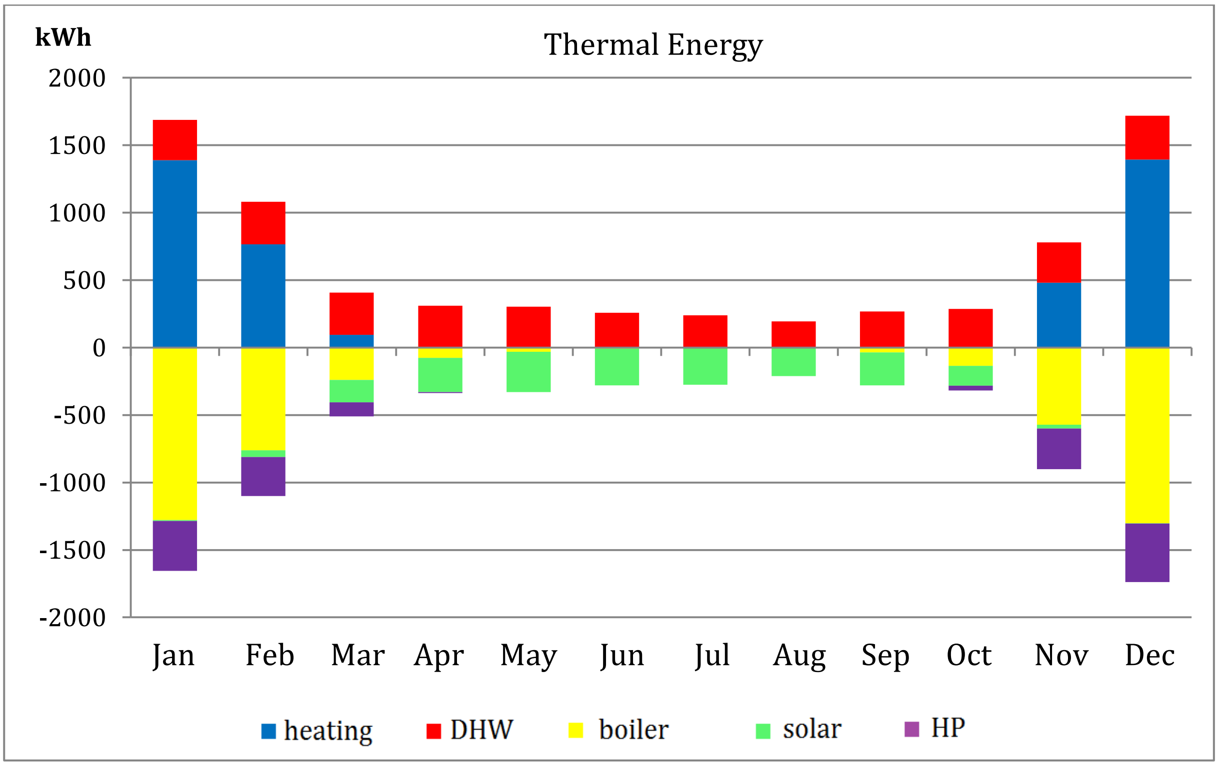


Figure 2. 35. Energy needed and provided- CASE B3

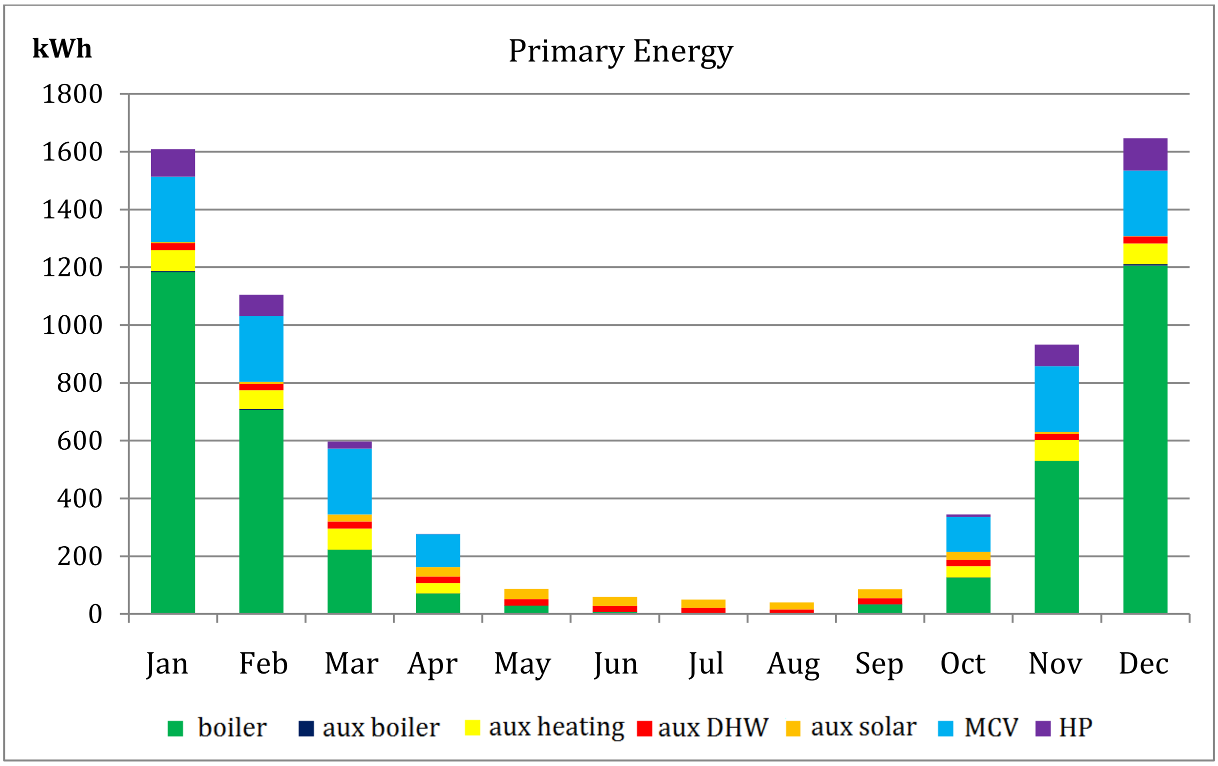


Figure 2. 36. Primary energy demand - CASE B3

The installation of the heat pump allows to limit the output energy of the boiler from 26.28 kWh/m^2 to 21:07 kWh/m^2, contributing with 7.28 kWh/m^2 to the fulfillment of the required load.
The energy demand is divided between a share of 54.27% for the space heating and a share of 45.73% for the DHW generation. The heat load is supply for the 56.12 % by the boiler, for the 24.48% by the solar collectors and for a share of 19.40 % from the heat pump.
The energy contribution due to the heat pump is significant in the coverage of global demand for heat energy, but by analyzing related primary energy demand the reduction, compared to the case B2, is not as significant. In Fact the primary energy demand decrease from 37.87 to 32.38 kWh/m^2, equal to saving of 14.5%. To determine the actual convenience in the installation of the heat pump it will be necessary to perform other kinds of analysis that go beyond the pure energy analysis performance.

2.5.8 CASE B4

As last case analysis, for comparison purpose, the same plant configuration (boiler + solar + heat pump) of the previous system was considered with the exception of employing fan coil units as system terminals. In fact, with reference to the CASE 0, the replacement of the radiators with fan coils represents a less invasive retrofit action respect to the installation of a floor heating system.
The Table 2.54 resumes the data and the parameter used in the simulation of the CASE B4, while the results of the simulation are presented in Table 2.55.

Table 2.54. Data and the parameter used in the simulation of the CASE B4.

SIMULATION DATA AND PARAMETERS CASE B4:condensing boiler ,heat pump, fan coils, solar collectors, CMV system		
BUILDING		
Transmittance coverage	W/m^2K	0.608
Transmittance of exterior walls	W/m^2K	0.269
Transmittance windows	W/m^2K	1.137
Air leakages	Vol/h	0.1
HVAC SYSTEM		
CONDENSING BOILER		
Power Rating	kW	24
Specific heat of fluid	kJ/kgK	4.186
PLR (capacity steps)	-	2
Set point temperature	°C	60
Generation efficiency η_{gen}	-	1.003
SOLAR COLLECTORS		
Aperture net area	m^2	6.9
Operative fluid specific heat	kJ/kgK	4.190
Design flow rate	kg/h	100
HEAT PUMP		
Power rating	kW	8.0
Design flow rate	kg/h	1800
Set point temperature	°C	Climatic control
MCV		
Daily hour of operation	h	24 (2 flow rate values)
Max air change rate (17h)	Vol/h	0.56
Min air change rate	Vol/h	0.1
CONTROLLER		
Th (upper input temperature)	°C	60
UDB (upper dead band)	°C	5
LDB (lower dead band)	°C	2
EMISSION SUB-SYSTEM – Fan coils		
Design flow rate	kg/h	3000
Set point temperature	°C	50
GENERAL		
Operation mode		continuous
Daily hour of operation	h	14
Emission efficiency η_{em}	-	0.91
Regulation efficiency η_{reg}	-	0.93
Delivery efficiency η_{distr}	-	0.981

Table 2.55. Results of the simulation carried out for the CASE B4

CASE B4	kWh	kWh/m^2
Dispersions trough the envelope (energy needs of the building, include solar gains and internal gains)	3649	17.29
transmission	3274	15.51
infiltration	375	1.78
Ventilation	2120	10.05
Energy demand for heating (include the overall efficiency of the system)	4283	20.03
Energy demand for DHW	3418	16.2
Total energy demand recorded at the tank	7457	35.34
Total energy supplied by the boiler to the tank	4909	23.26
Total energy supplied by solar collectors to the tank	1652	7.83
Total energy supplied by the heat pump to the tank	1141	5.41
Power absorbed by auxiliaries		
circulation pump boiler	9	0.04
heating circulation pump	219	1.04
DHW circulation pump	267	1.27
solar system pump	130	0.62
MCV fans	632	3.0
Compressor and circulators of the HP	372	1.76
Primary Energy	7223	34.23

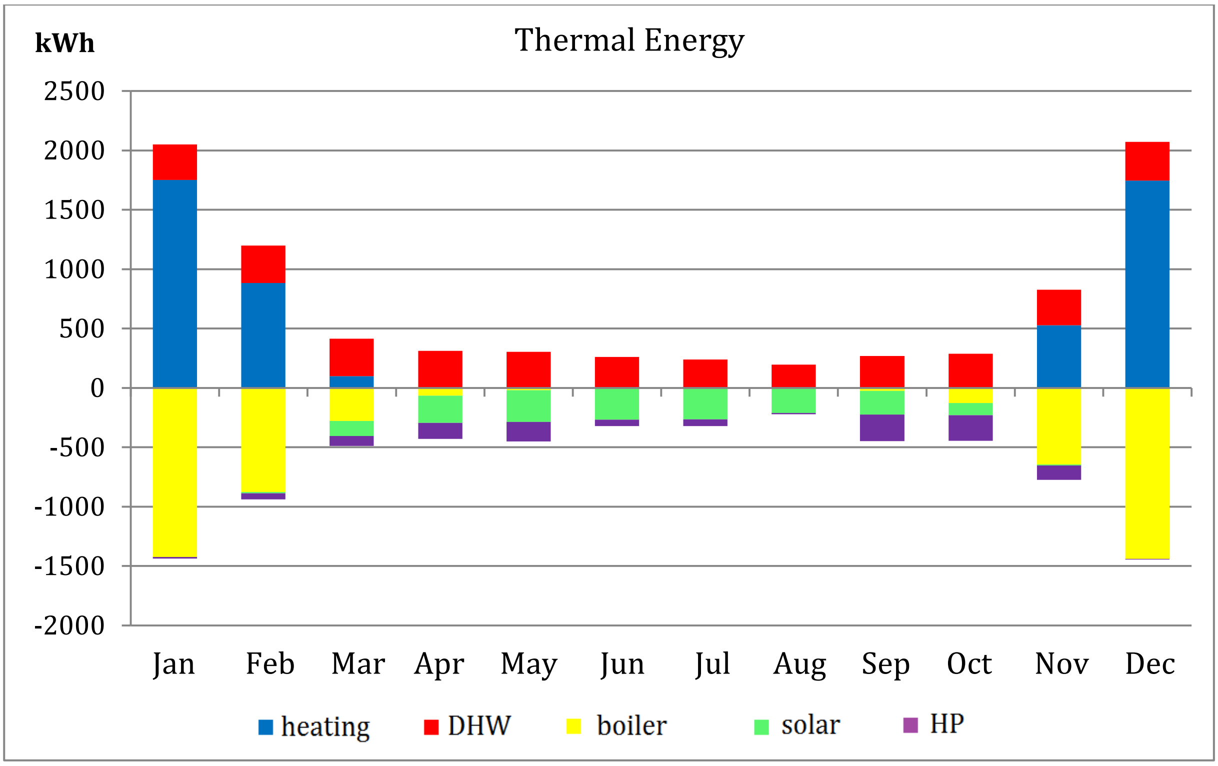


Figure 2. 37. Energy needed and provided- CASE B4

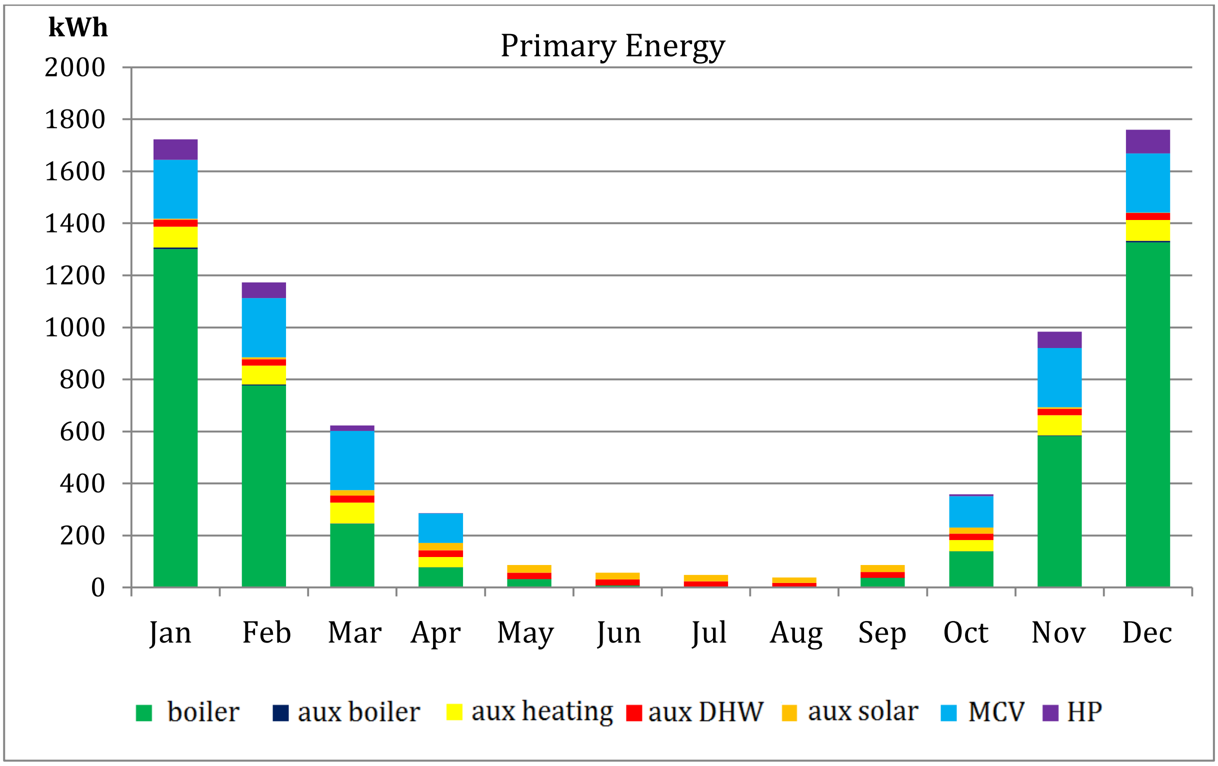


Figure 2. 38. Primary energy demand - CASE B4

In first analysis it can be seen as the primary energy demand, even maintaining a low value, is slightly higher respect to the CASE 3, where the system is equipped with floor radiant panels. The disappointing result, however, consists in the fact that the contribution of the heat pump, which is only lightly lower compared to the CASE B3 (16:28 % of the total), occurs in an undesired period. In fact, analyzing the trend of the monthly energy needs it can be seen how the heat pump integrates the functioning not of the boiler but of the solar collectors. During the summer the heat pump contribution is substantial, while in heating conditions, it is very low , and the thermal energy is mainly provided by the gab boiler. This results indicates a failure in the storage tank behavior, which cannot ensure a proper stratification, so that the heat pump is not able to find a proper area of operation in the tank thermal levels in heating conditions. Some justification can be provided: first of all the fact that the heat pump definitely fits better with the working temperature of the radiant panels rather than fan coils one, furthermore the chosen storage tank capacity (500 l) is not sufficient to ensure the desired stratification. It would probably be more appropriate but also more expensive to install a tank with a higher capacity or provide a second tank , in order to dedicate the first the production of hot water and the second to the space heating. This solution is largely recommended by theoretical analysis but presents very few application due to the increasing cost of the system, particularly referring to single houses, while it is more diffused in multi-family building solutions.

2.6 Conclusions

To better analyze the final picture of the simulations results a resuming of the energy performance of the case studies is presented. The energy demand of each solution is reported in terms of thermal and primary energy. Also the contribution of each generation sub-system of the HVAC facility is shown as well as the total contribution of renewable resources respect to total primary energy demand.

The chart of Figure 2. 39 shows a comparison between the thermal energy demand, divide by utilization, and the thermal energy supplied by the components of the HVAC system. CASE 0 refers to the ante-opera situation, the case study of the A group concern retrofit actions on the system but not on the building, and the cases of the B group consider retrofit interventions both on the system an on the building envelope.
In terms of thermal energy the retrofitting of the building envelope reduce the energy demand to less than the 30% of the initial value. This is a very consistent results, achieved with a proper action of insulation of the external surface of the building and the replacement of the windows with a double glazed solution equipped with gas argon into the chamber and low emissive treatment.
The same data are presented in Figure 2.40 in percentage terms to better understand the share of each generation sub-system on the thermal energy supplied.

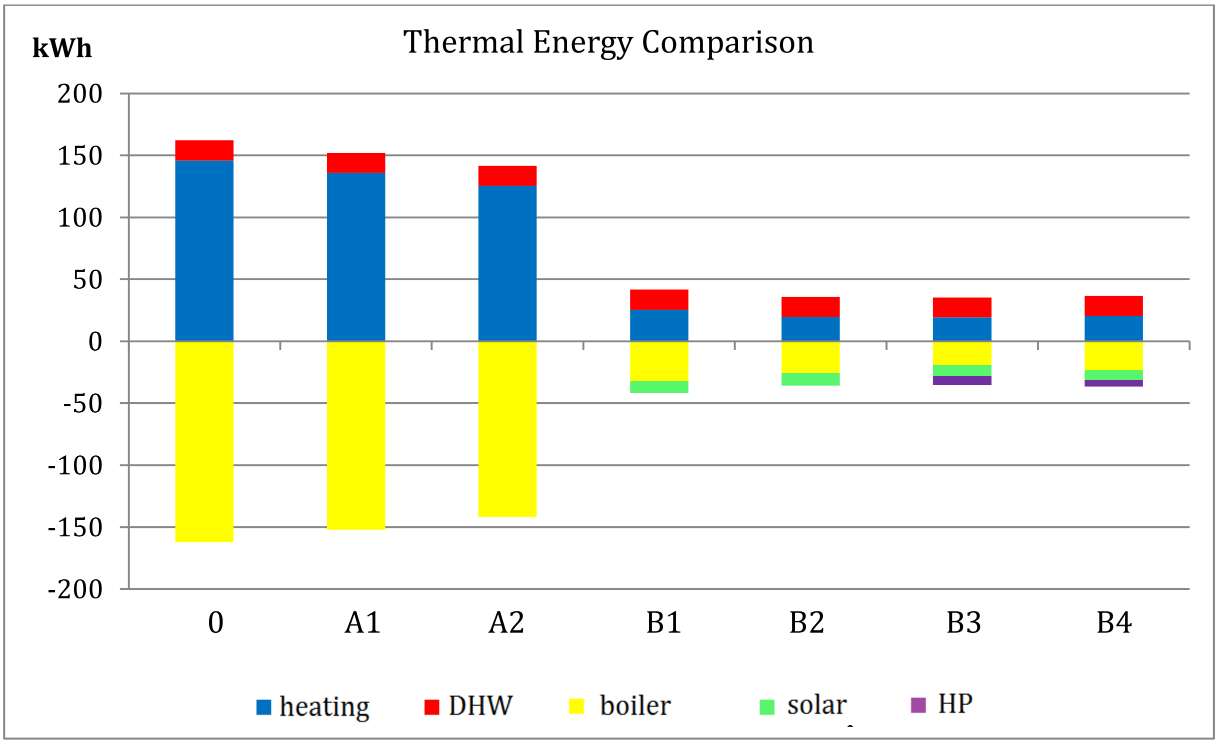


Figure 2. 39. Energy needed and provided- comparison

The Figure 2.41 present the comparison among the contribution of the renewable energy respect to the thermal energy provided by the HVAC system. The best solution among the case studied is the B3, with a 42.5% on renewable energy supplied, while the worst scenario is represented by the CASE B1 which achieve a renewable energy contribution of about the 23.1%.
According to primary energy the Figure 2.42 shows how the solutions A1 and A2 reduce the energy demand respectively of the 13.5 % and of 12.5% by replacing the conventional boiler with a condensing one, the difference between the two solution consist in the emission system which in the former is made by radiant floor panes and in the latter by cast iron radiator operating in low temperature.

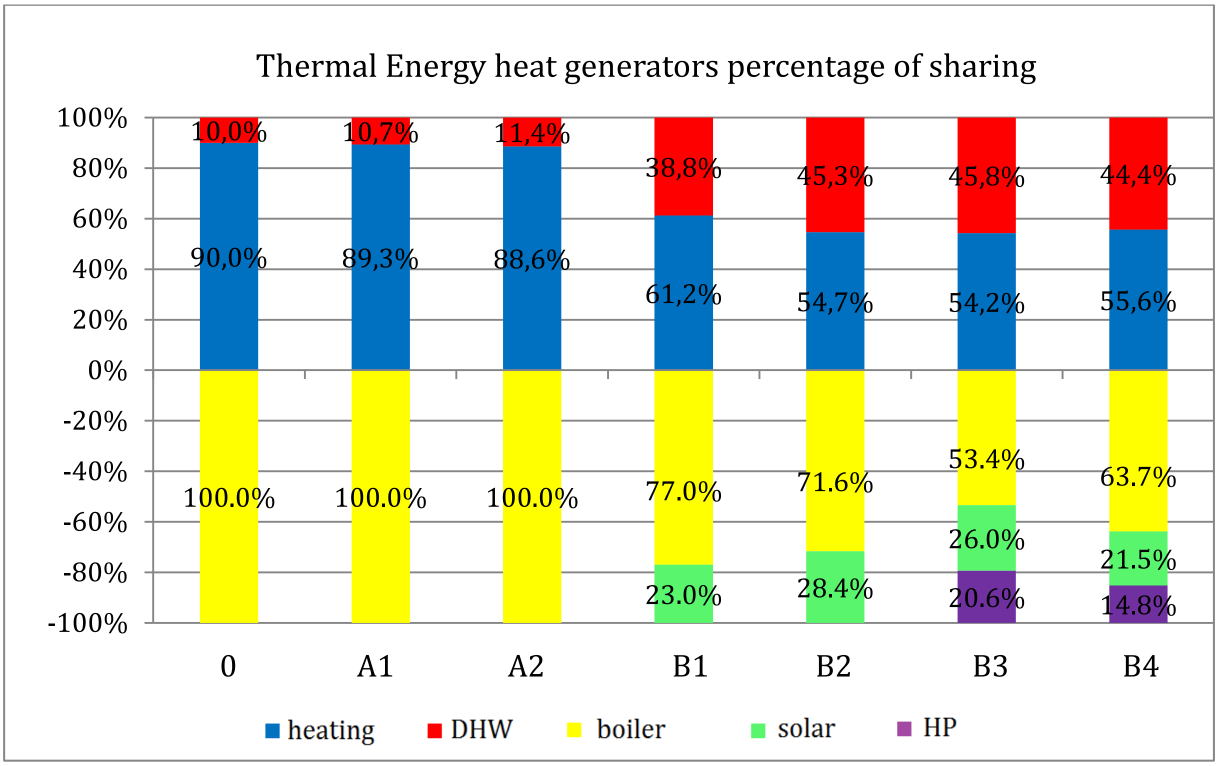


Figure 2.40. Energy needed and provided- percentage values comparison

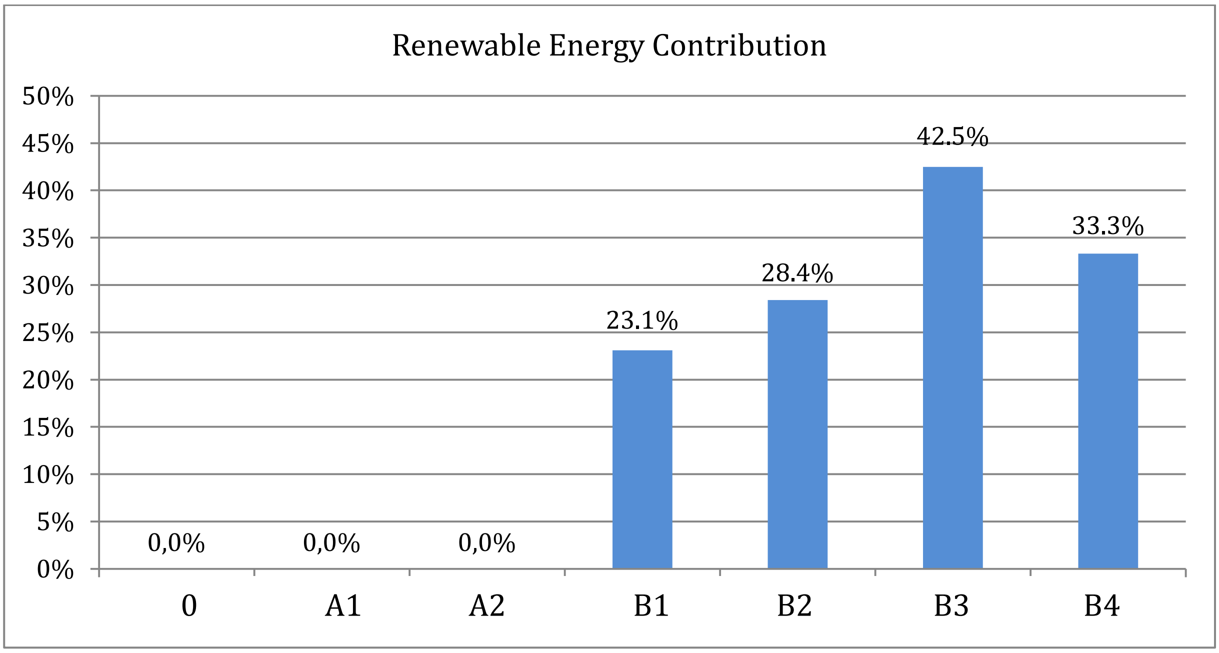


Figure 2.41. Renewable energy contribution comparison

The solution B1 can be considered as the reference condition of the retrofitted building: the system is equipped with a condensing boiler, a thermal solar system, radiators as emission devices and a MCV system. The solution B2 consider the same configuration for the heat generation components but employs radiant panels as emission system, achieving a primary energy demand reduction of about

15.7%. Cases B3 and B4 consider also the installation of an air-water heat pump, as integration to the heating system. This device allows a reduction of the energy demand equal, respectively of 28% and 24% respect to the solution B1.The difference between them is that the first employ a radiant floor system and the second fan coils.

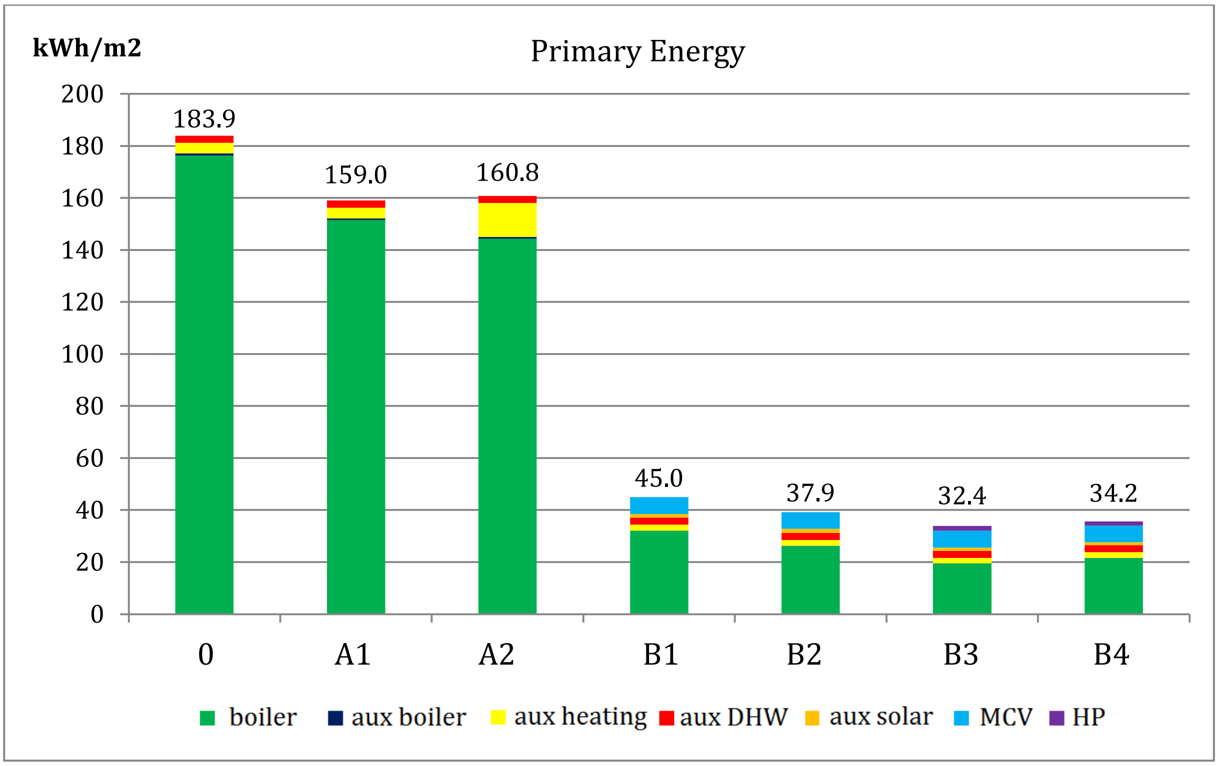


Figure 2.42. Primary energy demand - comparison

Some conclusion can be drawn: the graphs clearly highlight what has already been said about the comparison between operating at low temperature radiators and fan coil units: it is more convenient to work the low temperature radiators and more continuous operation rather than proceed to the replacement of existing terminals, at least as regards to the un retrofitted building conditions. The installation of the external insulation and the replacement of windows are endeed very effectiveactions, in fact they highly reduce the heating requirements of the building, decresing the big gap, that used to exist, between losses due to transmission and ventilation to a almost equilibrated situation. The supply of the solar plant, according to Italian regulation, has to meet more than 50% of the thermal energy requirement for the production of sanitary hot water and at least the 20% of the total thermal enrgy demand. The require is satified in every case analyzed.

The component from which it a greater contribution was surely expected is the heat pump, which in the best case covers the 20.8 % of the total energy required, while the boiler has to cover the remaining 53.4 % of the heat load integrated byy the soalr thermal collectors. As already discussed above the most plausible justification for this result is the not satisfactory dimension and configuration of the storage tank, which furthermore is very complex component to model.

In the and the dinamic simulations carried out, considering the fact that the components implemented were non-adapted ad hoc but chosen from commercial catalogs, have proved the energy effectiveness of the building and HVAC system redevelopment assumed at the beginning of the work.

2.7 References

[1] Official Journal of the European Union, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.
[2] D.P.R. 26 agosto 1993, n. 412(1).Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art.4, comma 4, della L.9 gennaio 1991, n. 10
[3] D.P.R. 16 aprile 2013, n. 74.Regolamento recante definizione dei criteri generali in materia di esercizio, conduzione, controllo, manutenzione e ispezione degli impianti termici per la climatizzazione invernale ed estiva degli edifici e per la preparazione dell'acqua calda per usi igienici sanitari, a norma dell'articolo 4, comma 1, lettere a) e c), del decreto legislativo 19 agosto 2005, n. 192. (13G00114)
[4] UNI/TS 11300-2 :2008 “Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale e per la produzione di acqua calda sanitaria” + EC1:2010
[5] UNI 10349:1994. Riscaldamento e raffrescamento degli edifici. Dati climatici.
[6] UNI/TS 11300-1:2008 “Determinazione del fabbisogno di energia termica dell’edificio per la climatizzazione estiva ed invernale” + EC1:2010
[7] UNI EN ISO 7730:2006. Ergonomia degli ambienti termici - Determinazione analitica e interpretazione del benessere termico mediante il calcolo degli indici PMV e PPD e dei criteri di benessere termico locale
[8] Final Report on DHW Load Profile, International Energy Agency, Annex 42.
[9] D.P.R. 15-11-1996 n. 660. Regolamento per l'attuazione della direttiva 92/42/CEE concernente i requisiti di rendimento delle nuove caldaie ad acqua calda, alimentate con combustibili liquidi o gassosi.
[10] Appunti dal corso di “Termotecnica”, Marco Mariotti, A.A 2011-2012.
[11] UNI EN 12975 -2. Impianti solari termici e loro componenti, Collettori solari.
[12] EN 12976-1:2006. Thermal solar systems and components. Factory made systems. General requirements
[13] UNI EN 12977:2012. Impianti solari termici e loro componenti - Impianti assemblati su specifica
[14] TRNSYS - © 2006 by the Solar Energy Laboratory, University of Wisconsin-Madison
[15] D.M. 26 gennaio 2010 “Aggiornamento del decreto 11 marzo 2008 in materia di riqualificazione energetica degli edifici
[16] UNI 15251 2008. Classi di Ventilazione Meccanica.

CHAPTER

3

DYNAMIC SYMULATIONS AND LABORATORY TESTS FOR THE ENERGY PERFORMANCE ANALYSIS OF AN INTEGRATED MULTI-ENERGY SYSTEM IN AN APARTMENT BUILDING

Abstract
The chapter will present an analysis carried out in collaboration with Sime Spa, Hiref Spa and the University of Padua. The activity aims to esteem the performance of an heating system built to service a multi- residential building. In particular, it aims to identify the configuration of the HVAC system that maximizes the contribution of the renewable energy resources, as solar energy and the renewable share due to the use of an heat pump.

The integrated system is capable of using thermal energy generated by the means of different sources, like as: natural gas, through a modulating condensing boiler, electrical energy, by means of a heat pump, and solar thermal energy, through a field of 30 glazed flat-plate collectors distributed in 6 arrays.

The building model analysis was carried out on the basis of a real project under construction: it is a multi- residential complex, consisting of 30 unit s, divided into two adjacent buildings with a total net area of about 2080 m² .

The operation of the HVAC system has been repeatedly analyzed by the computer numerical code TRNSYS in order to test different configurations and installations choices .

The focal points of the analysis were:

- *maximize the thermal efficiency of the solar system and its contribution to the energy supplied by the system;*
- *the modeling of the behavior of thermal storage, carried out in collaboration with the laboratory of research and development of Sime SpA, in order to set the mathematical model integrated in the code with the behavior of real storages.*

The analysis conducted can be divided into three phases. The first phase consists in the performance analysis of the HVAC system proposed by the designers. The aim was to maximize the generation of thermal energy from renewable sources and achieve on optimal integration between the heat generation subsystems installed. The second phase of the work has evaluated some changes both according to the design of the system both to the sizing of the installed components. A better coupling between the users energy demand and the energy supplied by the system was the desired goal. The solar circuit has undergone the major changes, in fact the contribution for heating purpose has been evaluated as not convenient, due to the low energy provided for that use respect to the cost of the installation, and the energy provided by the sola collectors has been released to the DHW circuit.

The final phase of the project was focused on the possibility to adapt the integrated multi-energy system to traditional buildings, equipped with non-insulated envelopes and with radiators as emissions devices.

3.1 Phase 1. Optimization of the Solar System

3.1.1 The Case Study

3.1.1.1 The Building

The case study has been modeled on the basis of the project a residential complex in an advanced stage of construction. It is a multi-residential complex with a net floor area of 2080 m², divided into two blocks semi-independent, A and B, respectively divided in 5 floors above ground and 4 floors above ground. The basement that serves as a garage, cellar and boiler room is shared.
The building highlighted in yellow in Figure 3.1 consists of a basement, a ground floor and four upper floors. The ground floor and the each raised fools contain four apartments for a total of twenty units. The building B, highlighted in orange, is composed of a basement, a ground floor and three upper floors. The ground floor and the raised floors contain three apartments with the reception of the attic where is located a penthouse is located. Globally the building B accommodates 10 residential units. Planes of the ground floors are presented in Figure 3.2 and Figure 3.2. Plane of the building A

.

Figure 3.1. Prospectus NORTH-WEST

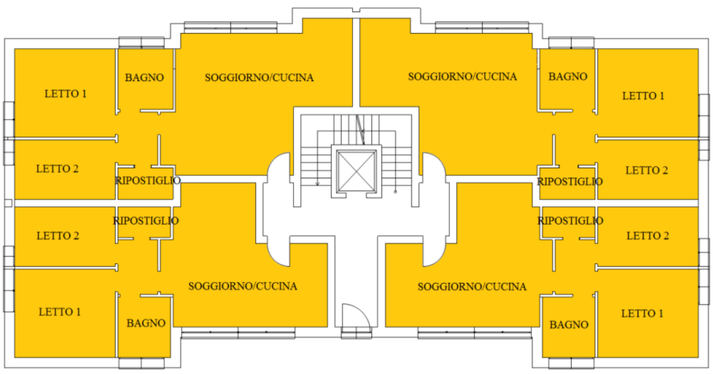


Figure 3.2. Plane of the building A

Figure 3.3. Plane of the building B

Regarding the structures of the building, basement floor, inter floor and external walls property are presented in Table 3.1 to Table 3.3. The stratigraphy presented, provided by the designer, have been used in implementation of the model of building for the dynamic simulations.

Table 3.1. External wall physical and thermal properties.

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0,130
Lime mortar or lime concrete	1800	1,5	0,9	0,020
Poroton 30 cm	800	30	0,276	1,090
Polystyrene 0036	30	10	0,036	2,780
Plastic plaster to coat	1300	0,5	0,3	0,020
Liminal outer layer				0,040
Total		42		4,080
U-Value				**0,246 [W/m²K]**

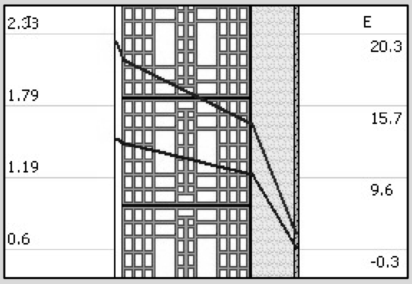


Table 3.2. Inter-floor physical and thermal properties.

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0,170
Ceramic tiles	2300	1,5	1	0,020
Background in lean concrete	2200	6	0,93	0,060
Acustic panel	23	3,5	0,038	0,920
Polical	450	10	0,11	0,910
Block attic 2.1.03i / 2240	1214	24	0,727	0,330
Lime mortar or lime concrete	1800	1	0,9	0,010
Liminal outer layer				0,170
Total		46		2,590
U-Value				**0,386 [W/m²K]**

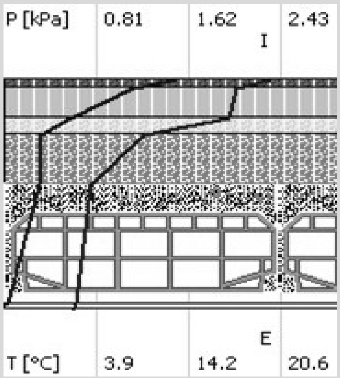
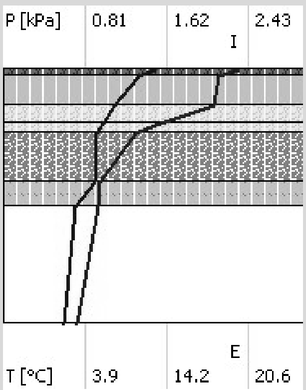


Table 3.3. Basement on garages physical and thermal properties.

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0,170
Ceramic tiles	2300	1,5	1	0,020
Background in lean concrete	2200	6	0,93	0,060
Acustic absorbing panel	23	3,5	0,038	0,920
Polystyrene 0036	30	2	0,036	0,560
Polical	450	10	0,11	0,910
Ordinary concrete	2200	5	1,28	0,040
Panel predalles 4-16-4	1200	24	0,354	0,680
Liminal outer layer				0,170
Total		52		3,530
U-Value				**0,284 [W/m²K]**



3.1.1.2 The radian floor system

The building in the analysis is served by the means of a radiant floor system. The radiant panels structure is presented in Figure 3.4. The pipes are made cross-linked polyethylene (PEX) with an outer diameter of 17 mm, an expanded polystyrene insulation of 35 mm thickness, that allows a minimum distance of pipe laying of 50 mm and a polystyrene sheath with a 0.4 mm thickness which fulfill the function of the vapor barrier. Each apartment is equipped with self- management controller of the radiating system based on continuous control of flow temperature .
In the building an external probe based control is installed, i.e. the delivery temperature is adjusted automatically depending on the outside temperature, in order to guarantee the best performance and the best home comfort. The control mode has been achieved by means of an electronic control unit and a external temperature probe. The laying scheme layout of the radiating system in the two analyzed buildings is given so as example in Figure 3.6 and Figure 3.7.

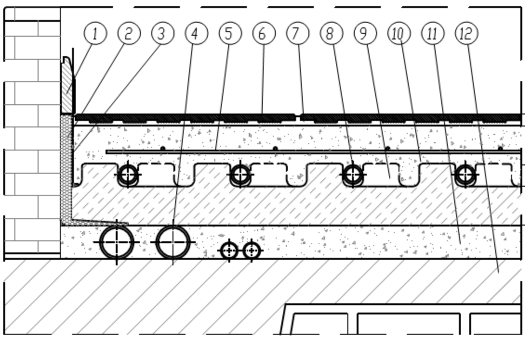


Table 3.4 Legend of the Figure 4

Index	Description
1	Skirting board
2	Ribbon perimeter
3	Film overlap
4	Technical installations
5	Reinforcing mesh
6	Paving
7	Glue for floors
8	PEX pipe
9	Insulation panel
10	Vapor barrier
11	Levelling screed
12	Rough attic

Figure 3.4. Radiant floor panel system

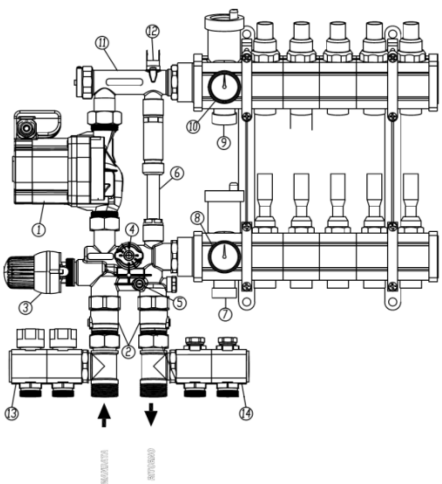


Figure 3.5. Manifold and control system of the floor radiant system

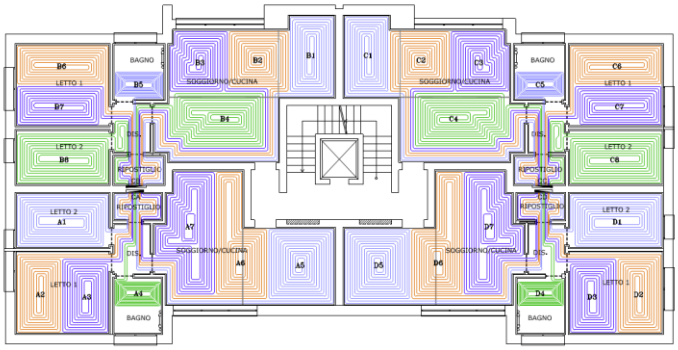


Figure 3.6 Plant of the scheme of laying the radiant system of Building A

Figure 3.7 Plant of the scheme of laying the radiant system of Building B

3.1.1.3 The HVAC system – the integrated multi-energy system (IMES)

The HVAC system solution proposed by designers for the heating system involves the use of 30 plane solar thermal collectors, a gas fed modulating condensing boiler and an air-water heat pump. The energy provided by these components is stored within 3 thermal storage, two of them dedicated to the DHW production and the latter to the satisfy of the heating demand.

The solar collectors are plane glazed units and the flow circulation is forced by a solar pumping group. Each collector is characterized by a net absorber area of 2.30 m², and has a maximum carrier fluid capacity of 2.12 liters and a design flow rate of 180 kg/h .

The solar field is made up of 6 batteries of 5 collectors connected in parallel. The described layout derives from a compromise between the optimization of the load losses and the thermal difference between the carrier fluid inlet outlet trough the collectors. The arrays are oriented facing the South-West orientation and a installed with a slope of 45° respect to the horizontal plane. The batteries are properly spaced to comply with the shading factor. Technical features of the collectors are provided in Figure 3.8 and Table 3.5. The gas condensing boiler is a premixed boiler for wall installation, composed by 3 identical modular generators. Each module has a sealed chamber unit, a forced air draft. The overall power rate is of about 284.7 kW, the installed solution guarantee low emissions performance and high value of efficiency equal to 98.2% in design load condition and to 108% at 30% Partial Load rate (PLR), the maximum allowed operating temperature is 85 °C. Design features are provided in Figure 3.9 and Table 3.6. The heat pump is a split system, that means that it is divided between an outdoor unit and an indoor unit. The two units are connected through the house by copper piping. The outdoor unit houses a coil that acts as a heat exchanger and compressor. The indoor unit houses a coil and a fan. The fan housed in the indoor unit circulates air through the home's ventilation system. Freon gas acts as a coolant as it passes through the copper piping, between both coils (indoor unit and outdoor unit). Heat is absorbed from the air by the Freon gas. The refrigerant gas used in the considered device is R410A. The installed heat pump has a design heating power of 151.2 kW, with an outdoor dry bulb temperature of 7 °C, a delivery water temperature equal to 35°C and a water nominal capacity of 26000 l/h. Technical data are presented in Table 3.7 and Table 3.8. The two storage tanks intended for the DHW have a capacity of 2000 liters (Table 3.9 and Figure 3.10). The shell is made in carbon steel, glazed inside, and externally insulated with a soft polyurethane layer with 100 mm thickness. Two coiled heat exchanger are immersed in the inner volume. The top coil is dedicated to the boiler circuit, while in the lower one circulates the brine of the solar circuit. The two coils have different geometric characteristics: the first has an 3 m² exchange area and a fluid capacity of 18.5 liters, the second has a 4.5 m² net heat exchange surface of a capacity of 27.7 liters. The two tanks are arranged in parallel. The third heat storage tank (Figure 3.11 and

Table 3.12), intended for the storage of hot water for heating also presents a volume of 2000 liters, it is made of carbon steel S235JR and has an outer insulation of soft polyurethane with 100 mm thickness, but unlike the formers is equipped with a single coil heat exchanger connected with the solar circuit, placed in the lower part of the volume. According to the configurations of the fluid flows within the tank, the flows provided by the boiler and the heat pump are conveyed to the storage, where they mixed within the inner volume, as well as the return water from the radiant floor system, while the brine coming from the solar system circulates inside the coil heat exchanger. The plane of the IMES configuration is presented in the Figure 3.12.

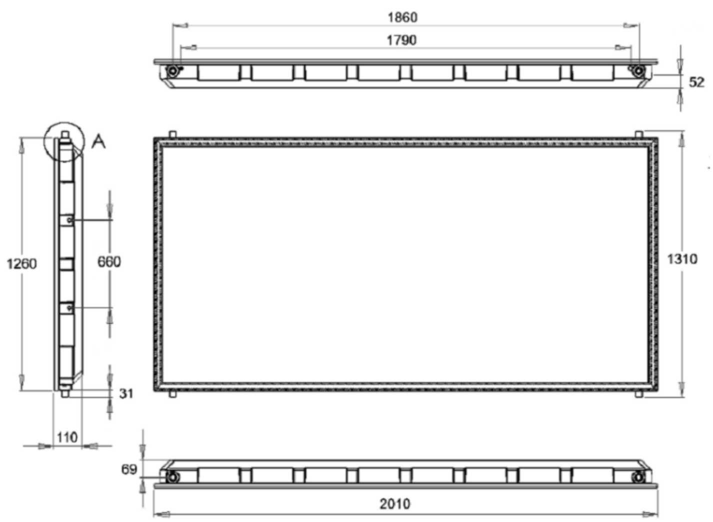


Figure 3.8. Solar thermal collector design, section and prospectus

Table 3.5 Solar thermal collectors technical features.

Item	Value

Gross collector surface	2,51 m²
Absorbing net surface net	2,30 m²
Fluid capacity	2,12 l
H_0 according to en 12975	0,76
A_1 according to en 12975	4,54
A_2 according to en 12975	0,012
IAM (50 °)	0,80
Fluid heat capacity	7,86 kJ/m²K
Absorption coefficient	95% ± 2%
Transmission coefficient	5% ± 2%
Maximum operating pressure	10 bar
Stagnation temperature	173,8 °C
Dimensions of the manifold	2010 x 1260 x110 mm
Collector case	Aluminum for naval application
Weight of the empty collector	45,4 kg

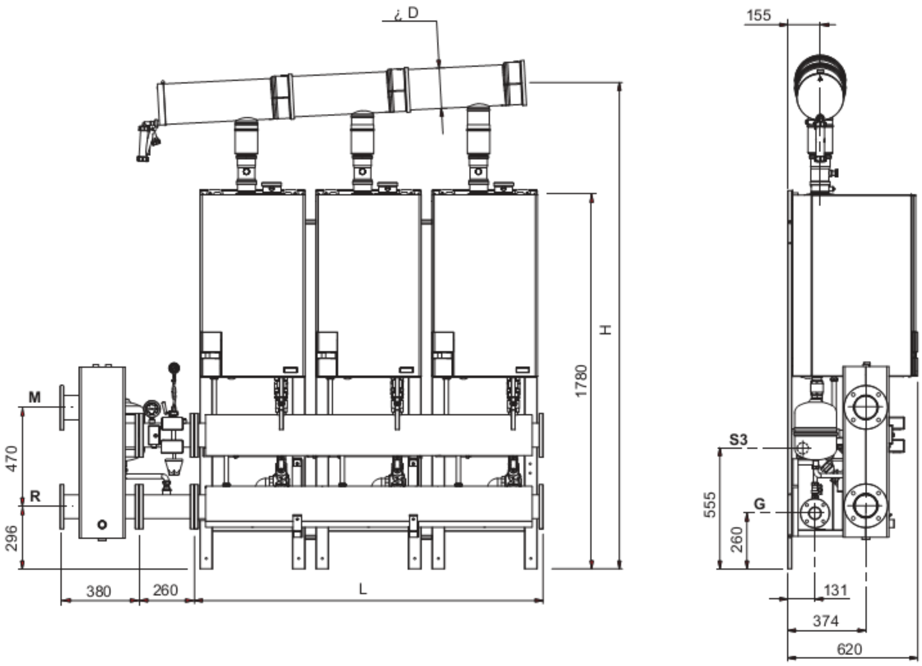


Figure 3.9. Gas condensing modulating boiler P330

Table 3.6. Technical features of the boiler P330

Item	Value
Nominal heat output	324 (3 x 108) kW
Minimum heat output	21,6 kW
Nominal heat output 80/60 °C	316,8 (3 x 105,6) kW
Nominal heat output 50/30 °C	343,8 (3 x 114,6) kW
Minimum heat output 80/60 °C	21,1 kW
Minimum heat output 50/30 °C	23,6 kW
Energy performance (92/42)	4 stars
Efficiency at 30% (40/30 °C)	105,6 %
Efficiency Min / Max 80/60 °C	97,7/97,8%
Efficiency Min / Max 50/30 °C	109,1/106,1%
Arrest losses at 50 °C	378 (3 x 126) W
Water content modules	24,6 (3 x 8,2) l

Maximum operating temperature	85 °C
Maximum operating pressure	5 bar
Dimensions	1656 x 2326 x 620 mm

Table 3.7. Heat pump technical features

Item	Value
Heat output 40/45 °C and 7 °C	151,2 kW
Design water flow	25999 l/h
Exchanger pressure drops	36 kPa
Power input	42.2 kW
Evaporator inlet temperature min / max	15/45°C
Condenser inlet temperature min / max	12/25°C
Maximum operating pressure (water)	3 bar
Refrigerant	R410A
Dimensions	1794 x 2374 x 872 mm
Empty weight	1205 kg

Table 3.8. technical features of the finned coil, heat pump component

Item	Value
Air flow	23860 m³/h
Power consumption	1205 W
Absorbed current	5,5 A
Maximum current consumption	7,6 A
Weight	312 kg

Table 3.9. Technical features of the DHW storage tank 2S 2000

Item	Value
tank Volume	2000 l
Maximum Operating Pressure	10 bar
Maximum operating temperature	95°C
Maximum operating pressure coils	10ber
Maximum operating temperature coils	110°C
Exchange surface coil at the top	3,0 m²
Exchange surface bottom coil	4,5 m²
Capacity of the coil at the top	18,5 l
Capacity of the bottom coil	27,7 l
Power consumption serpentine top	58 kW
Power consumption lower coil	56 kW
Required flow serpentine top	2,45 m³/h
Required flow serpentine top	2,45 m³/h
Pressure drop serpentine top	36,6 mbar
Pressure drop bottom coil	53,6 mbar
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) upper coil	1800 l/h
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) bottom coil	2900 l/h
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) upper coil	74 kW
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) bottom coil	115 kW
Thickness of insulation	100 mm
Insulation	Soft polyurethane foam
Empty weight	485 kg

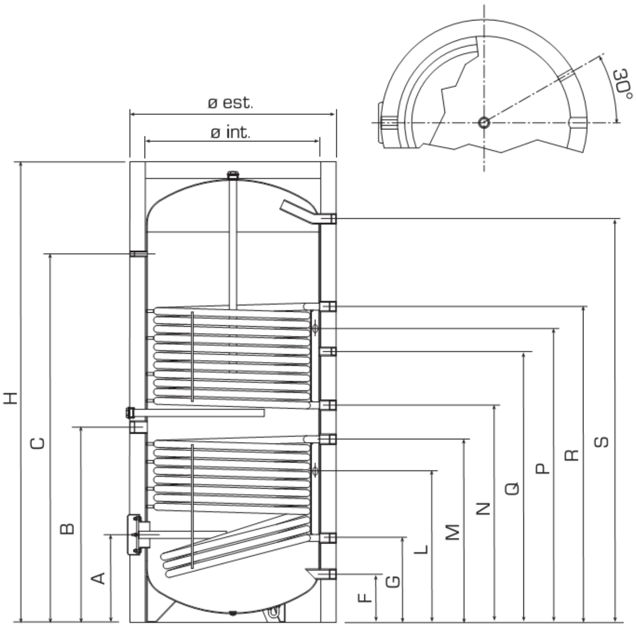


Figure 3.10. DHW storage tank 2S 2000

Item	Value
A Flange	550 mm
B Electrical resistance 1 ½"	1310 mm
C Thermometer ½ "	2090 mm
F Cold water 1 ¼ "	340 mm
G Return the solar circuit 1 1/4 "	460 mm
L Probe circuit solar ½ "	985 mm
M Solar circuit flow 1 ¼ "	1160 mm
N Heating return 1 ¼ "	1450 mm
P Heating probe ½ "	1825 mm
Q Recirculation 1 "	1650 mm
R Heating flow 1 ¼ "	2000 mm
S Hot water 1 ¼ "	2210 mm
H Total height	2550 mm
ø est Outer diameter (with insulation)	1300 mm
ø int Inner Diameter (without insulation)	1100 mm

Table 3.10. Geometrical features of the DHW storage tank 2S 2000

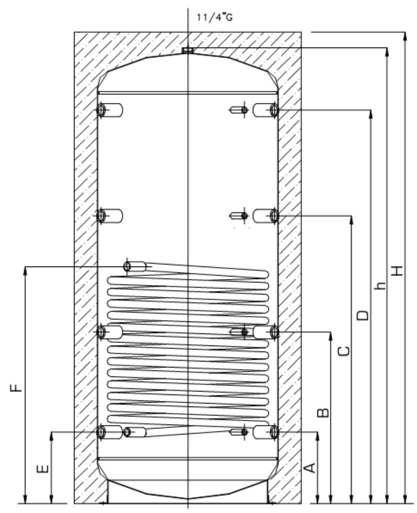


Figure 3.11. Heating thermal storage Puffer 1S 2000

Item	Value
A Attack / Probe / duct probe	328 mm
B Attack / Probe / duct probe	884 mm
C Attack / Probe / duct probe	1441 mm
D Attack / probe / probe duct	1998 mm
E Back exchanger	328 mm
F Flow heat exchanger	1131 mm
h Height without insulation	2328 mm
H Height with insulation	2408 mm
ø est Diameter with insulation	1300 mm
ø int Diameter without insulation	1100 mm
ø thread	1 ½ “
Attack probe ø thread	½ “
Attack exchanger ø thread	1 “

Table 3.11. Geometrical features of the heating storage Puffer 1S 2000

Table 3.12. technical features of the heating storage Puffer 1S 2000

Item	Value
Tank volume	1930 l
Maximum operating pressure	3 bar
Maximum operating temperature	95°C
Coil maximum operating pressure	10 bar
Coil maximum operating temperature	110°C
Coil exchange surface	4,2 m²
Coil fluid capacity	26,6 l
Coil heat absorption power	120 kW
Coil design maximum flow rate	4,5 m³/h
Coil pressure drop	51 mbar
Hot water generation Δt 35°C (80°/60°C - 10°/45°C)	1420 l/h
Hot water generation Δt 35°C (80°/60°C - 10°/45°C)	57 kW
Insulation thickness	100 mm
Insulation type	Soft polyurethane foam
Empty weight	270 kg

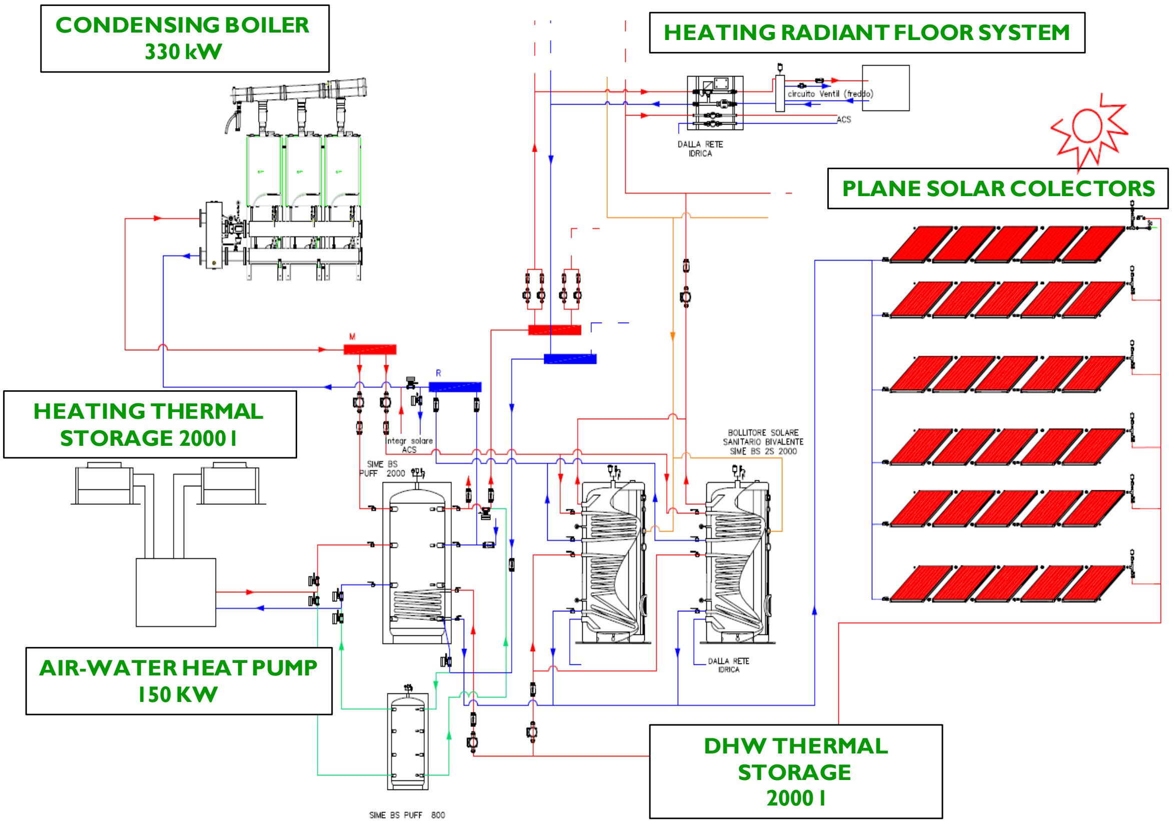


Figure 3.12. Map of the IMES (Integrated Multi-Energy System)

3.1.2 Preliminary Simulations

3.1.2.1 The Software

The software TRNSYS[1] as described in the users manual of the code is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc. TRNSYS applications include: solar systems (solar thermal and PV), low energy buildings and HVAC systems with advanced design features (natural ventilation, slab heating/cooling, double façade, etc.), renewable energy systems, etc.
TRNSYS consists of a suite of programs: The TRNSYS Simulation Studio, the simulation engine (TRNDll.dll) and its executable (TRNExe.exe), the Building input data visual interface (TRNBuild.exe), and the Editor used to create stand-alone redistributable programs known as TRNSED applications (TRNEdit.exe). The main visual interface is the TRNSYS Simulation Studio. From there, you can create projects by drag-and-dropping components to the workspace, connecting them together and setting the global simulation parameters. The simulation Studio also includes an output manager from where you control which variables are integrated, printed and/or plotted, and a log/error manager that allows you to study in detail what happened during a simulation.

3.1.2.2 Methods

The first phase of the activity carried out was aimed to identify the best system configuration in order to optimize the solar system energy supply. The creation of the model by the means of the numerical code TRSNSYS was realized implementing the components of the HVAC system according to the technical feature and the parameters presented in the previous paragraph. A draft of the Simulation Studio worksheet is presented in Figure 3.13.
The data necessary to the modelization of the solar collectors are the ambient temperature, the total radiation incident on horizontal , the radiation diffused on horizontal and the total radiation along the titled surface of the collector.
The accumulation tanks are modeled as cylindrical vessels with a vertical axis, insulated with a 10 cm thick layer of polyurethane. Each tank is divided, for modeling purpose, into a vertical succession of volume elements, called nodes, to better represent the natural stratification inside the storages. A node represent a section of the inner volume of the tank which is suppose to have an isothermal temperature level. The software user can control the intensity of the stratification by varying the number of nodes of the tank model. Each node interacts with neighboring ones through exchanges of energy, by conduction and convection of heat, and through mass exchanges due to the mixing effect of the flows conveyed at the storage inlet and outlet. The nodes are numbered from the top to the bottom and it is up to the user to specify to which nodes the ports of the tank are placed. The modeling of the accumulation was performed with the intention of obtaining the highest possible detail degree, for this purpose 20 nodes have been considered, the maximum allowed by the software. A description of the models implemented for the storage tanks are is provided in Figure 3.14 and in Figure 3. 15.

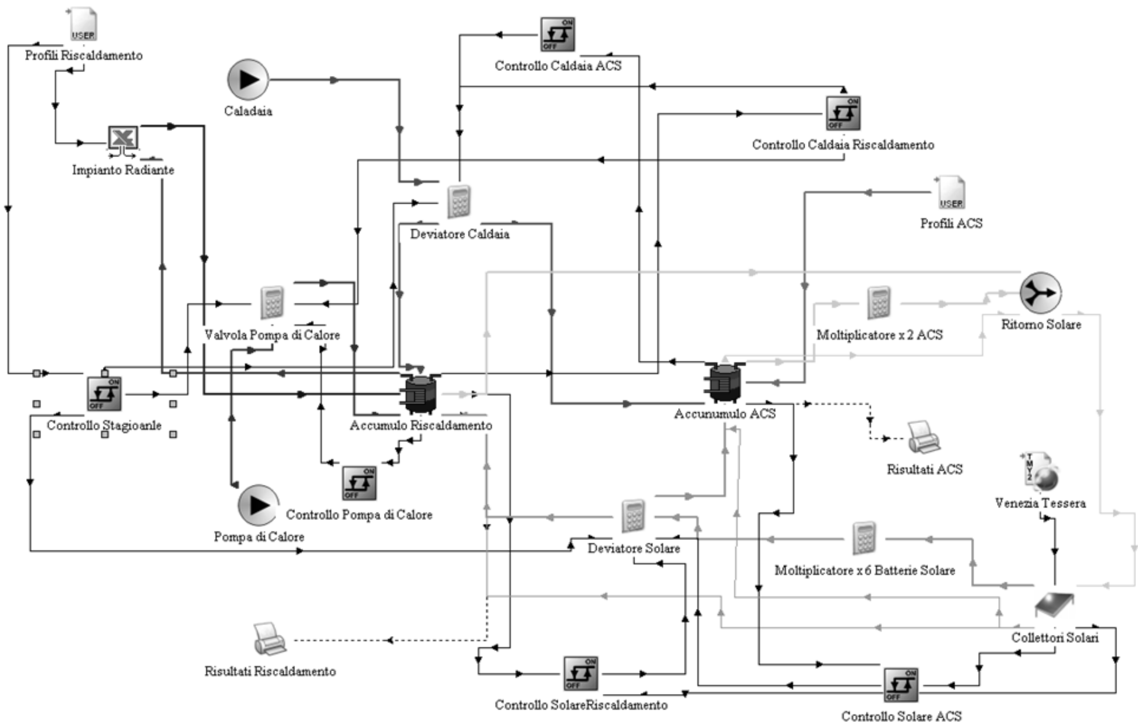


Figure 3.13. diagram of the Simulation Studio model of the HVAC system

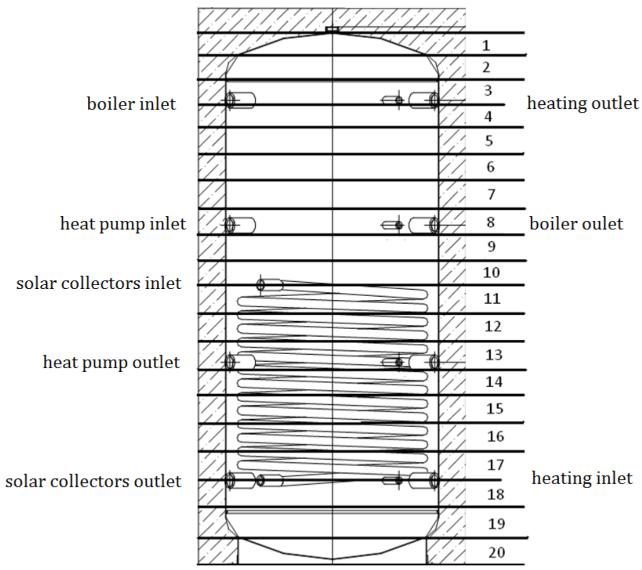


Figure 3.14. Volume elements modeling for the heating tank

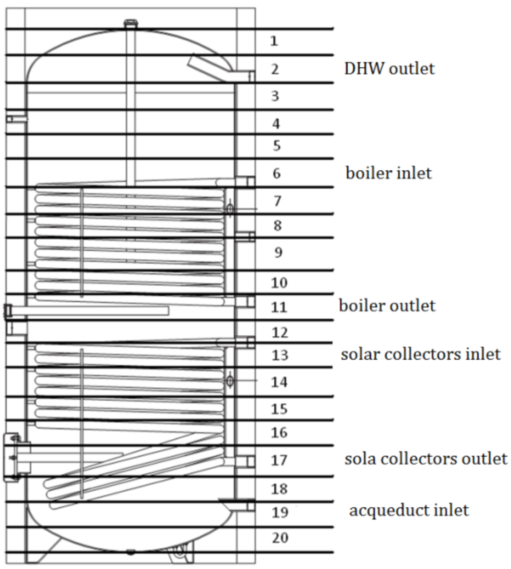


Figure 3. 15. Volume elements modeling for the DHW tank

The logic of control of the solar circuit aims to avoid the phenomena of the thermal inversion, so the activation of the flow circulation in this circuit is subject to the achievement of a positive differential temperature between the outlet temperature from the collectors and the temperature of t node corresponding to the inlet into the tank. Proper controls manage the ignitions of the condensing boiler and deliver the hot water flow to the DHW generation section of the plant or to the heating section. The boiler, as well as the heat pump, in the simplified case, works with a fixed value temperature set-point, in particular the boiler operates with an outlet temperature of 80 °C , higher than the desired flow temperature for the heat generation of both DHW (75 °C) and heating (50 °C). Regarding the heat pump the temperature set-point, set to 40 °C , is not greater than the desired temperature of the heating flow (it is recalled that the heat pump does not intervene on the accumulation of the ACS), and the activation control operates with a logic similar to the solar collectors one, based on a positive differential temperature between the outlet of the machine and the temperature at the inlet node. The output of the simulation are the thermal loads for the DHW generation and the space heating of the analyzed building and the amount of the energy supplied by HVAC system. Since it is an integrated multi- energy in particular amount and percentage values of the contributions of the involved energy sources are investigated.

3.1.2.3 Energy loads

The preliminary simulations, conducted in the initial phase of the research to asset the energy performance of the solar system, have been realized before the modelization of the case study building. For his reason the heating loads and energy requirements for the DHW generation were esteemed by standard trends derived from previous activities on multifamily residential complex.

3.1.2.4 Results

The first set of simulations were made to assess if acting on the management of the solar circuit flow was possible to increase the solar energy contribution. In particular, the aim was to define the best share of flow to attribute to each of the storage tanks in order to maximize the renewable energy supply. The simulation run by 15 minutes simulation steps for an overall period of two years. The results refer to the second year of analysis in order to assure the independence from the set initial condition. In Table 3.13 a resume of the performed simulations is presented. The table presents a brief description of the system configuration and the label associated with each case. The Table 3.14 and the Table 3.15 present the simulation results according to the energy supplied for respectively heating and DHW generation. The Table 3.16 resumes the total amount of the energy supplies.

Table 3.13. Resuming of the preliminary phase performed simulation

Case Description – Solar Flow Partition	**CODE**
Case with a constant flow pump (50% DHW - 50% Heating)	A1
Case with a constant flow pump (66.6% DHW - 33.3% Heating)	A2
Case with constant flow pump for heating and variable flow pump for DHW (DHW50% - 50% Heating)	B1
Case with constant flow pump for heating and variable flow pump for DHW (DHW 66.6% - 33.3% Heating)	B2
Case with a single constant flow pump and diverter valve (50% DHW - 50% Heating)	C1
Case with a single constant flow pump and diverter valve (66.6% DHW - 33.3% Heating)	C2
Case with constant flow pump upstream and diverter valve downstream regulated with P-type control (DHW 50% - 50% Heating)	D1
Case with constant flow pump upstream and diverter valve downstream regulated with P-type control (DHW 66.6% - 33.3% Heating)	D2

Table 3.14. Thermal energy supplied for heating

	BOILER		SOLAR SYSTEM		TOTAL INPUT	
HEATING	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	94253	45.31	430	0.21	94750	45.55
A2	94335	45.35	343	0.16	94745	45.55
B1	93953	45.17	659	0.32	94680	45.52
B2	94195	45.29	461	0.22	94724	45.54
C1	93859	45.12	739	0.36	94666	45.51
C2	94115	45.25	580	0.28	94762	45.56
D1	85948	41.32	884	0.43	86901	41.78
D2	86206	41.45	690	0.33	86965	41.81

Table 3.15. Thermal Energy supplied for the DHW generation

	BOILER		SOLAR SYSTEM		TOTAL INPUT	
DHW	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	25499	12.26	18350	8.82	43849	21.08
A2	22036	10.59	22094	10.62	44130	21.22
B1	18323	8.81	27424	13.18	45747	21.99
B2	18176	8.74	27577	13.26	45752	22.00
C1	18322	8.81	27427	13.19	45748	21.99
C2	18164	8.73	27591	13.26	45755	22.00
D1	18489	8.89	27350	13.15	45839	22.04
D2	18311	8.80	27535	13.24	45847	22.04

Table 3.16. Total amount of the thermal energy supplied

	BOILER		SOLAR SYSTEM		TOTAL INPUT	
HEATING + DHW	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	119752	57.57	18780	9.03	138599	66.63
A2	116371	55.95	22437	10.79	138876	66.77
B1	112276	53.98	28083	13.50	140427	67.51
B2	112371	54.02	28039	13.48	140477	67.54
C1	112181	53.93	28166	13.54	140415	67.51
C2	112279	53.98	28171	13.54	140518	67.56
D1	104438	50.21	28235	13.57	132740	63.82
D2	104518	50.25	28226	13.57	132812	63.85

Table 3.17. Heat sources sharing according to heating

HEATING SOURCES SHARING	BOILER	SOLAR SYSTEM
A1	99.47%	0.45%
A2	99.57%	0.36%
B1	99.23%	0.70%
B2	99.44%	0.49%
C1	99.15%	0.78%
C2	99.32%	0.61%
D1	98.90%	1.02%
D2	99.13%	0.79%

Table 3.18. Heat sources sharing according to DHW gereation

DHW SOURCES SHARING	BOILER	SOLAR SYSTEM
A1	58.15%	41.85%
A2	49.93%	50.07%
B1	40.05%	59.95%
B2	39.73%	60.27%
C1	40.05%	59.95%
C2	39.70%	60.30%
D1	40.34%	59.66%
D2	39.94%	60.06%

Table 3.19. Heat sources sharing of the total energy amount

TOTAL SOURCES SHARING	BOILER	SOLAR SYSTEM
A1	86.40%	13.55%
A2	83.80%	16.16%
B1	79.95%	20.00%
B2	79.99%	19.96%
C1	79.89%	20.06%
C2	79.90%	20.05%
D1	78.68%	21.27%
D2	78.70%	21.25%

According to the presented results some considerations can be drought. As expected, the proportional controller of the solar circuit operative flow is more effective than the on-off control. It means that is actually possible to increase the energy contribution of solar system, acting not directly on the collectors field, but improving the solar system integration within the other components of the system, in this case with specific refer to the storage tank.

According to the results the solar system contribution to the energy supplied to satisfy the heating demand is very low. This is not surprising due to the weather data used in the simulation. In fact, the winter period, during which the energy demand for heating is higher, is the most unfavorable for the exploitation of the solar source. According to the test Reference Year (TRY) of Venice [2], the winter average outdoor temperature is not suited to the use of a flat solar collector even if glazed, also fog is common during the heating season and it can be present for almost the entire day, interfering with the irradiation of the collectors.

The small contribution of the solar system with respect to the heating demand has questioned whether or not to maintain this circuit of the system. In fact, the economic benefits, that would result from the choice of erasing it, would be considerable (the elimination of the sophisticated system for the flow diversion management , the elimination of one heat exchanger in the storage, the elimination of the pipes of the circuit) and they exceed the financial return given by the energy savings. Nevertheless it has to be noticed that the discussed simulations are still affected by many simplifications, so such choice has been better evaluated in the second phase of the activity.

Even the heat pump provides a modest contribution to the production of water heaters, due to the fact that consistent approximations were made in the simplified model. The heat pump, were modeled to provided water at the predetermined temperature of 40 °C; the temperature has been deliberately kept low trying to forcing the device ignition even in winter typical outdoor temperatures. The results are so modest that the voice of the heat pump has been deleted from the tables exposed as insignificant.

Considering the low contributions of the solar system and heat pump it is obvious that the heating energy demand has been ensured by the condensing boiler, which is operating efficiently in winter conditions, since its performance are not related to the outside weather.
Regarding the generation of DHW the cases with a subdivision of 33% of the solar circuit flow between the three storages (simulation with the index 2) show an higher energy contribution of the solar system respect to the simulations where distribution of flow rate was equally divided between the heating and DHW generation sections of the system (simulation with the index 1).
It has to be noted that the solar collector energy input is always higher than the 50% of the total thermal energy provided to satisfy DHW energy demand, with the only exception of the solution that implemented the constant flow circulators, which represents the less efficient logic control. This achievement is significant because it confirm that the analyzed HVAC system, even in the simplified configuration modeled into the preliminary simulations, is able to provide an enough share of renewable resources, as demanded by the Italian regulation [3] The norm requires that all the new building and the retrofitted ones should provide at least the 50% of the DHW energy demand and the 20% of the overall energy demand by renewable sources.
The energy contribution provided by the solar system respect to the DHW generation is much higher of the one according to heating demand, due to the fact that the demand for sanitary water is extended for the whole year and because in summer the solar collectors work with high efficiency for many hours a day. Furthermore in systems with variable flow rate, during the summer period when the heating system is turned off, all the flow from the solar collectors is conveyed to the DHW generation section.

3.1.3 Final Simulations

3.1.3.1 Methods

The second phase of the research activity has aimed to eliminate most of the simplifying assumptions introduced in the preliminary simulations. In the first place, was given ample attention to improve the modeling of thermal storages. As the place of the integration among the energies provided by the several heat generation sub-system, they are affected by consistent flow rate exchanges between the circuits of the system and the inner volume. Therefore they are subjected to a highly dynamic operation, with important transient, very difficult to be analyzed by the means of the basic models provided with the software. A great effort has therefore made to improve the models of the TRNSYS library. Through a fruitful collaboration with the laboratory of research and development of SIME SpA, laboratory tests have been performed with the purpose to calibrate the model of thermal storage to the behavior of the real tanks. The report of laboratory tests, with the explanation of the procedures and methods used in the analysis, and the presentation of the results and of the changes operate to the storage models are shown in the Annex 1.
The second important improvement introduced with respect to the preliminary simulations was the implementation of a more functional and efficient model for the heat pump, thanks to the collaboration with SIME S.p.a. and Hiref S.p.a.
The purpose of the final simulations is to identify the best performing design solution according to the management of the solar system , taking into account the results provided by the preliminary simulations, and to assess how it is possible to increase the performance of the system by acting on the various components such as the boiler , the heat pump and the management and control system. In

particular, it is necessary to asses if the HVAC performance are able to satisfy the requirements of the Italian regulation [1]
According to the results of the experimental phase of calibration of the storage model, the first important change introduced in the model of the HVAC system was the corrections of the features and the parameters of the tanks. The modified data are presented in Table 3.20.

Table 3.20. Corrections according the storage tanks models

Item	Value
Volume of the heating tank	1.62 m³
Coil length of the heating tank heat exchanger	44 m
Coil length of the DHW tank boiler heat exchanger	36 m
Coil length of the DHW tank solar heat exchanger	63 m

Another changing concerns the setting of the water delivery temperature of the radian system, a control based on the outdoor temperature, tested with an external probe, has been introduced. The external probe control provided the set point temperature of the radiant system according to the value of the outdoor air temperature. With external temperature lower than -5°C the delivery temperature is set to the maximum value of 38°C, with external temperature higher than 15°c the delivery temperature is set to 22 °C, in the range between the two threshold the delivery temperature is set on the basis of the mathematical Equation (1), showed in Figure 3.1. On the basis of the low temperature needed by the radiant system the set point temperature of the boiler and of the heat pump could be fixed.

$$y = 34 - 0{,}8x \tag{1}$$

where x correspond to the outdoor temperature and y to the set temperature of the heating system.

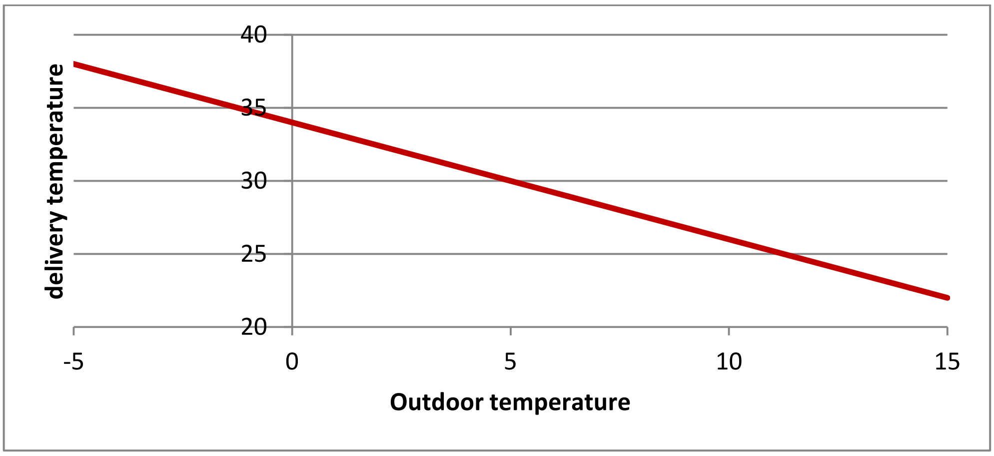


Figure 3.16. Delivery temperature of the heating system according to the outdoor temperature

The boiler, compared to simulations of the first phase , was modeled with a more performing component take from the TRNSYS library, and suitably implemented on the basis of the operating curve of the real component, so as to be able to replicate the behavior of the machine in whole field of modulation.
The heat pump has been implemented by the means of an Excel spreadsheet developed, calibrated on the bases of the operative data of the evaporator and of the condenser, provided by the manufactures.

As it is known, the performance in terms of COP of a heat pump depends on the thermal conditions to which the heat exchangers (evaporator and condenser) of such a machine may operate. In particular, since the analyzed heat pump is an air-water machine, the condenser transfers heat to the water that feeds the storage of the heating system and the evaporator absorbs heat from the outside. The better performance could be achieved with the increase of the outside air temperature or the decrease of the water temperature.
The external temperatures of the site of construction of the building are not always advantageous for the operation of a heat pump. In fact, in winter conditions such temperature drops even a few Celsius degrees below 0 value, and the effective COP value fall down, so it is necessary a considerable consumption of electrical energy which penalizes the use of the heat pump rather than the condensing boiler. Please note that the actual COP of an air-water heat pump is usually about half the theoretical COP.
The determination of the COP limit, the threshold value, that indicates the convenience to produce heat through the boiler or heat pump, derives both from economic and environmental aspect, according to the Equation (2)

$$COP_{limit} = [x\, COP_{environmental} + (1-x) COP_{economical}] \tag{2}$$

where x = 0÷1.

It is an operator choices whether to prefer between an economic convenience or a lower environmental impact: in the first case the generator used is the one which needs the minimum costs for the energy supply, in second case the generator which guarantee the lower emission of equivalent CO_2. Although nothing prevents you to make a choice somewhere in between the two extremes. It has to be noticed, however, that the choice between economic return and environmental impact are not necessarily in contrast, since, in many cases, a condition automatically satisfied the other.

The limit environmental COP value is obtained by comparing the emissions of CO_2 (and/or NO_x) between the boiler and the heat pump and is calculated by the Equation (3):

$$COP_{environmental} = \frac{CO_{2\,poewr\,plant}}{CO_{2\,boiler}} \frac{\eta_{boiler}}{100} \tag{3}$$

The limit economic COP value is a function of the cost of energy (both electricity and natural gas) and of efficiency of the boiler. The mathematical relation is presented in the Equation (4)

$$COP_{economical} = \frac{PCI \frac{\eta_{boiler}}{100} €_{kWh\,electricity}}{€_{kWh\,natural\,gas}} \tag{4}$$

Choosing an x value equal to 0.5, according to the Equation (2), the obtained threshold value for the COP limit is equal to 2.5.

Table 3.21. Parameters for the calculation of the limit value for the heat pump COP

Item	Value
CO_2 power plant	0.50 kg CO_2 /kWh
CO_2 boiler	0.25 kg CO_2 /kWh
η boiler	97.7%
PCI natural gas	9.59 kWh/m³.
$€_{kWh}$ electricity	0.3 €/kWh
$€_{kWh}$ natural gas	0,93 €/m³

The Excel spreadsheet for the heat pump modeling requires as input the outdoor temperature, the relative and specific humidity values, the temperature and the water flow at the pump inlet and the device temperature set-point. In addition to these data, fundamental for the calculation of the COP, a heating seasonal control is required, in order to turn off the machine during the summer period, and a control on the tank temperature to prevent inverse temperature phenomena.

The code provides as output the outlet water temperature, the evaporation temperature, the power exchanged in the condenser and the evaporator, the electrical power absorbed by the compressor, and then the COP in the effective operation conditions. The Excel spreadsheet is integrated into TRNSYS in order to automate the calculation of the output data and automatically compare the effective COP with the limit value. If the instantaneous values is lower than the threshold limit, the heat pump is turned off, until the condition changes. In order to use the available heat generators in order of convenience (energy/economic) another control has been implemented to turn off the boiler if the heat pump is sufficient to guarantee the fulfillment of the heating requirements of the building.

Regarding the setting:

- the boiler set-point temperature, according to the DHW demand, has been fixed at 60 °C with an on-off control and a dead band equal to + / - 2 °C.
- the solar system is controlled on the basis of the temperature differential between the collectors outlet and the temperature of the tank node where the inlet is placed, with a dead band equal to +8 / -4 ° C

To ensure the hygienic conditions demanded by the law, the tanks for the preparation of the DHW are subjected to periodic sanitary cycles to prevent the formation of the legionella bacterium [4]. The cycles works on the thermal shock procedures, maintaining the storage inner volume at a temperature of 70 °C for period of 45 minutes every 3 days.

The modelization of the analyzed building has allowed the evaluation of the heating energy demand, calculated on the basis of the Venice TRY (Test Reference Year).

TRNBuild is the module of TRNSYS that allows the implementation of the characteristics of the building envelope, by dividing the building into thermal zones adjustable in a different way. The model created is composed by nine thermal zones, one for each floor of the two buildings. The definition of building model requires the implementation of the building external and internal structures and of the glazed elements, such as windows and doors. With regard to the internal and external walls, the model refers to the data provided by the designer and already presented in the paragraph 3.1.1.1.

Regarding the glass elements, in the absence of other data, standard elements, present in the library of the calculation code, were employed: a double glazed solution 4-16-4 with argon gas filled chamber and low emissivity treatment has been chose, which realizes a U-value equal to 1.4 W/m^{2}K .

The results of the energy performance of the building envelope have asset an heating energy demand for the case study equal to 33 kWh/m² per year.

In addition to the thermal requirement, the building model gives the values of the water flow necessary for the operation of the radiant systems. The rated capacity of each zone is shown in the Table 3.22.

Table 3.22. Water flow rate of the radiant floor systems

Item	Value
Zone 1 - Ground floor apartment A	3010 kg/h
Zone 2 - First floor apartment A	3010 kg/h
Zone 3 - Second floor apartment A	3010 kg/h
Zone 4 - Third floor apartment A	3010 kg/h
Zone 5 - Fourth floor apartment A	3010 kg/h
Zone 6 - Ground floor apartment B	1800 kg/h
Zone 7 - First floor building B	1800 kg/h
Zone 8 - Second floor building B	1800 kg/h
Zone 9 - Penthouse apartment B	1200 kg/h

3.1.3.2 Results

The changes described in the preceding paragraphs, and introduced the simplified model used in the first phase of the research, led to the modeling of a system much closer to the real one, able to replicate with a certain reliability the conditions of operation of the analyzed HVAC system.
Following the results of the performed detailed simulations are presented, the Table 3.23 shows, for a better comprehension, the summary of the considered cases.

Table 3.23. Case description for the detailed simulations

Case Description – Solar Flow Partition	CODE
Case with a constant flow pump (50% DHW - 50% Heating)	A1
Case with a constant flow pump (66.6% DHW - 33.3% Heating)	A2
Case with a single constant flow pump and diverter valve (100% DHW - 0% Heating)	B0
Case with a single constant flow pump and diverter valve (50% DHW - 50% Heating)	B1
Case with a single constant flow pump and diverter valve (66.6% DHW - 33.3% Heating)	B2

Table 3.24. Simulations results – Heating - all boiler modules operating in parallel

	BOILER		HEAT PUMP		SOLAR SYSTEM		TOTAL INPUT	
HEATING	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	33724	16,21	54642	26,27	1121	0,54	89487	43,02
A2	33984	16,34	53996	25,96	1114	0,37	89094	43,02
B0	33748	16,23	55266	26,57	1096	0,11	90110	43,02
B1	33844	16,27	54829	26,36	1106	0,45	89778	43,02
B2	33869	16,28	55307	26,59	1103	0,36	90279	43,02

Table 3.25. Simulations results – DHW generation - all boiler modules operating in parallel

	BOILER		SOLAR SYSTEM		TOTAL INPUT	
DHW	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	12473	6,00	29184	14,03	41657	20,03
A2	12570	6,04	28999	13,94	41568	19,98
B0	12482	6,00	28529	13,72	41011	19,72
B1	12518	6,02	28777	13,83	41294	19,85
B2	12527	6,02	28698	13,80	41225	19,82

Table 3.26. Simulations results – Total - all boiler modules operating in parallel

	BOILER		HEAT PUMP		SOLAR SYSTEM		TOTAL INPUT	
TOTAL	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	46197	22,21	54642	26,27	30306	14,57	131144	63,05
A2	46554	22,38	53996	25,96	30113	14,48	130663	62,82
B0	46230	22,23	55266	26,57	29625	14,24	131121	63,04
B1	46361	22,29	54829	26,36	29882	14,37	131072	63,02
B2	46396	22,31	55307	26,59	29800	14,33	131503	63,22

Table 3.27. Sources energy sharing – Heating - all boiler modules operating in parallel

HEATING SOURCES SHARING	BOILER	HEAT PUMP	SOLAR SYSTEM
A1	37,69%	61,06%	1,25%
A2	38,14%	60,61%	1,25%
B0	37,45%	61,33%	1,22%
B1	37,70%	61,07%	1,23%
B2	37,52%	61,26%	1,22%

Table 3.28. Sources energy sharing – DHW generation - all boiler modules operating in parallel

DHW SOURCES SHARING	BOILER	SOLAR SYSTEM
A1	29,94%	70,06%
A2	30,24%	69,76%
B0	30,44%	69,56%
B1	30,31%	69,69%
B2	30,39%	69,61%

Table 3.29. Sources energy sharing – Total - all boiler modules operating in parallel

TOTAL SOURCES SHARING	BOILER	HEAT PUMP	SOLAR SYSTEM
A1	35,23%	41,67%	23,11%
A2	35,63%	41,32%	23,05%
B0	35,26%	42,15%	22,59%
B1	35,37%	41,83%	22,80%
B2	35,28%	42,06%	22,66%

Considering the number of changes made in the evolution from the preliminary to the final model, it is not surprising that the results show different energy contributions with respect to the simplified case. First of all, it has to be noted as for all solutions is greatly increased the energy contribution of the heat pump, that in the second phase has been modeled in detail .

Another observation is according to the energy contribution of the solar system, which is higher in constant flow pumps solutions (cases A), unlike in the first analysis. A constant flow circulators imply that the solar collectors are subject to the nominal capacity only in the contemporary demand for DHW and heating condition. So the flow in the solar collectors is therefore smaller than the design value for the most of the time, and on equal solar incident radiation, undergoes to a greater increase of temperature which induces the differential control to increasing the amount of solar energy transferred to the system.

The worst results occurs for the solution B0 where a diverter feeds alternately the two circuits, in this case the heating circuit is disadvantaged, being always given priority to the DHW, as confirm the results of Table 3.29. As already in the preliminary analysis , the configuration with the equal distribution of flow rate between DHW and heating (index 1) is more advantageous, in all cases, with respect to the subdivision of the nominal flow rate to 33% among the tanks (index 2).

According to the fact that the boiler is composed by three modules arranged in parallel, it has been evaluated another system configuration in which the operation of the modules has been managed separately. The idea is that if a module of the boiler is dedicated to the DHW generation while the other two are maintained to satisfying the heating energy demand, the boiler can be splitted in two separated devices that can be controlled independently to better meet the temperature needs according to each service. In the previous analysis the boiler set-point temperature could only be fixed according to the minimum temperature level able to satisfy the sanitary water demand. In the suggested configuration the set point temperature could be, instead, so imposed:

- at 60 °C with an on-off control and a dead band equal to + / - 2 °C for the DHW module
- equal to the radiant panels delivery temperature plus 10 °C with an on-off control and a dead band equal to + / - 2 °C for heating modules

allowing the two components to operate with higher efficiency values. The results are presented in Table 3.30 to Table 3.35.

The results show how the possibility to perform a better modulation of the power of the boiler allows to obtain a considerable energy saving. In fact a lower average internal temperature of the heating storage allows heat pump to operate the with a greater COP and allows a greater exploitation of the solar system that increases by about half a percentage point. It is important to note that it was possible to increase the performance of the solar system, acting only on the distribution of flow rates and regulation, also the separation of the boilers can be performed without altering the design choices made, being the boiler made by the union of modular units. Finally, the modules dedicated to the heating demand managed with a lower temperature, work more frequently in condensing condition with higher efficiency value.

Table 3.30. Simulations results – Heating - boiler modules operating in splitted mode

	BOILER		HEAT PUMP		SOLAR SYSTEM		TOTAL INPUT	
HEATING	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	18913	9,82	63918	30,73	1019	0,49	83851	41,04
A2	18915	9,80	64217	30,87	1013	0,49	84145	41,16
B0	19283	10,08	64450	30,99	996	0,48	84729	41,55
B1	18863	10,03	63719	30,63	1005	0,48	83587	41,14
B2	18974	10,05	63985	30,76	1002	0,48	83961	41,29

Table 3.31. Simulations results – DHW generation - boiler modules operating in splitted mode

	BOILER		SOLAR SYSTEM		TOTAL INPUT	
DHW	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	15677	6,81	29286	14,08	44964	20,89
A2	15608	6,80	29100	13,99	44708	20,79
B0	16251	7,00	28629	13,76	44880	20,76
B1	16469	6,96	28877	13,88	45346	20,84
B2	16425	6,97	28798	13,85	45223	20,82

Table 3.32. Simulations results – Total - boiler modules operating in splitted mode

	BOILER		HEAT PUMP		SOLAR SYSTEM		TOTAL INPUT	
TOTAL	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²	kWh	kWh/m²
A1	34590	16,63	63918	30,73	30306	14,57	128814	61,93
A2	34523	16,60	64217	30,87	30113	14,48	128853	61,95
B0	35534	17,08	64450	30,99	29625	14,24	129609	62,31
B1	35332	16,99	63719	30,63	29882	14,37	128933	61,99
B2	35399	17,02	63985	30,76	29800	14,33	129184	62,11

Table 3.33. Sources energy sharing – Heating - boiler modules operating in splitted mode

HEATING SOURCES SHARING	BOILER	HEAT PUMP	SOLAR SYSTEM
A1	22,56%	76,23%	1,22%
A2	22,48%	76,32%	1,20%
B0	22,76%	76,07%	1,18%
B1	22,57%	76,23%	1,20%
B2	22,60%	76,21%	1,19%

Table 3.34. Sources energy sharing – DHW generation - boiler modules operating in splitted mode

DHW SOURCES SHARING	BOILER	SOLAR SYSTEM
A1	34,87%	65,13%
A2	34,91%	65,09%
B0	36,21%	63,79%
B1	36,32%	63,68%
B2	36,32%	63,68%

Table 3.35. Sources energy sharing – Total - boiler modules operating in splitted mode

TOTAL SOURCES SHARING	BOILER	HEAT PUMP	SOLAR SYSTEM
A1	26,85%	49,62%	23,53%
A2	26,79%	49,84%	23,37%
B0	27,42%	49,73%	22,86%
B1	27,40%	49,42%	23,18%
B2	27,40%	49,53%	23,07%

The comparison among the cases analyzed have has been done also in terms of primary energy: on the basis of the overall gross energy demand, including the thermal losses according to the boilers and the electricity needed to operate the heat pump compressor. The auxiliary energy needs have not been evacuate in this analysis.
The primary energy conversion coefficients have been derived according to the Italian law [5].The assumed value are presented in Table 3.36.

Table 3.36. Conversion coefficients according to primary energy calculation

Efficiency associated with natural gas	90%	→	1 kWh_t = 1/0.9 = 1.1 kWh_{EP}
Efficiency associated with the electricity grid	46%	→	1 kWh_{el} = 1/0.46 = 2.17 kWh_{EP}

For a further comparison a traditional heat generation system composed only by a conventional gas boiler was considered. On the basis of annual energy demand of the case study, the overall energy supplied by has been evaluated according to the requirements for heating and domestic hot water generation, the obtained value are respectively, equal to 68.64 MWh and 41.6 MWh, assuming an overall generation efficiency of about 0,875. According to the data presented, an annual consumption of energy equal to 125.99 MWh has been estimated, equivalent to 10,83 toe.
The results of the final comparison are presented in Table 3.37 and in Figure 3.17. The results show hoe and integrated multi-energy system like the object of the analysis, despite a higher cost of installation, ensures up to 4 tep savings of primary energy per year, and a consequent reduction of the greenhouse gas emissions, compared to a conventional system powered by a conventional gas boiler. The solution with two distinct boilers achieves an overall savings in terms of primary energy of 0.47 toe compared to the case with single boiler. Even if it has an increase in the heat pump primary energy demand, it is clearly offset by a grater reduction in the demand of the boiler.

Table 3.37. Simulation results - Primary energy needs

	BOILER		HEAT PUMP		SOLAR SYSTEM		TOTAL INPUT	
	Thermal energy [MWh]	Primary energy [tep]	Thermal energy [MWh]	Primary energy [tep]	Thermal energy [MWh]	Primary energy [tep]	Thermal energy [MWh]	Primary energy [tep]
IMES united	45,44	3,91	16,07	3,01	30,30	-	91,82	6,92
IMES separated	34,29	2,94	18,80	3,51	30,31	-	83,40	6,45
Conventional boiler	125,99	10,83	-	-	-	-	125,99	10,83

According to greenhouses gas emission, the IMES solution allows to significantly reduce the CO2 equivalent emissions to 20 tons per year, versus a value of 33.5 on per year of the conventional system. The value of greenhouse gas emissions were calculated using an emission factor equal to 3.1 t CO_2/tep [6].

Table 3. 38. Simulation results - CO_2 Emissions

	BOILER [t CO_2]	**HEAT PUMP** [t CO_2]	**TOTAL** [t CO_2]
IMES united	12,12	9,33	21,45
IMES separated	9,11	10,88	20,00
Conventional boiler	33,57	-	33,57

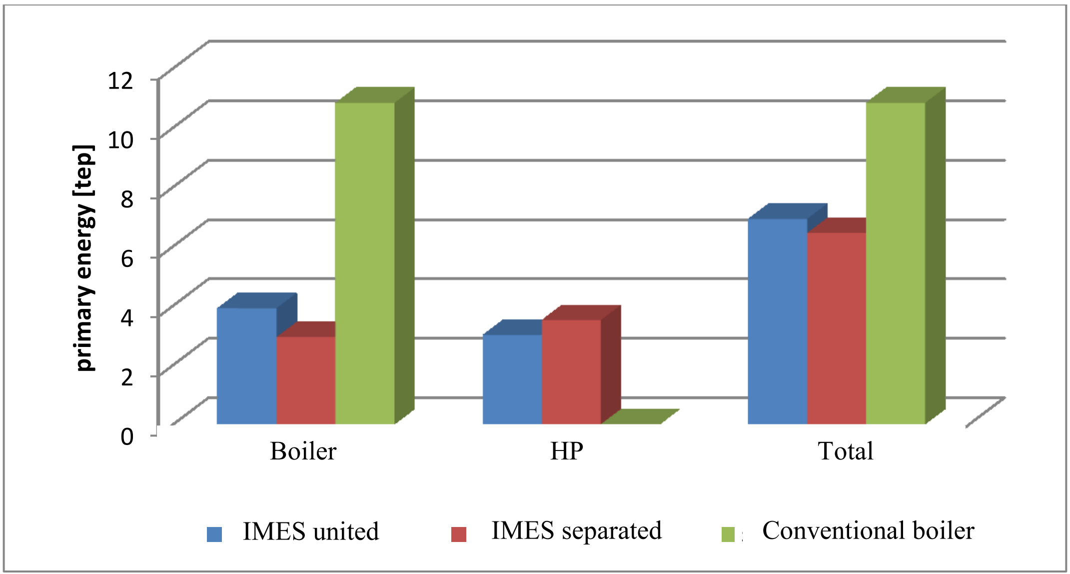


Figure 3.17. Simulations results - Primary energy demand comparison

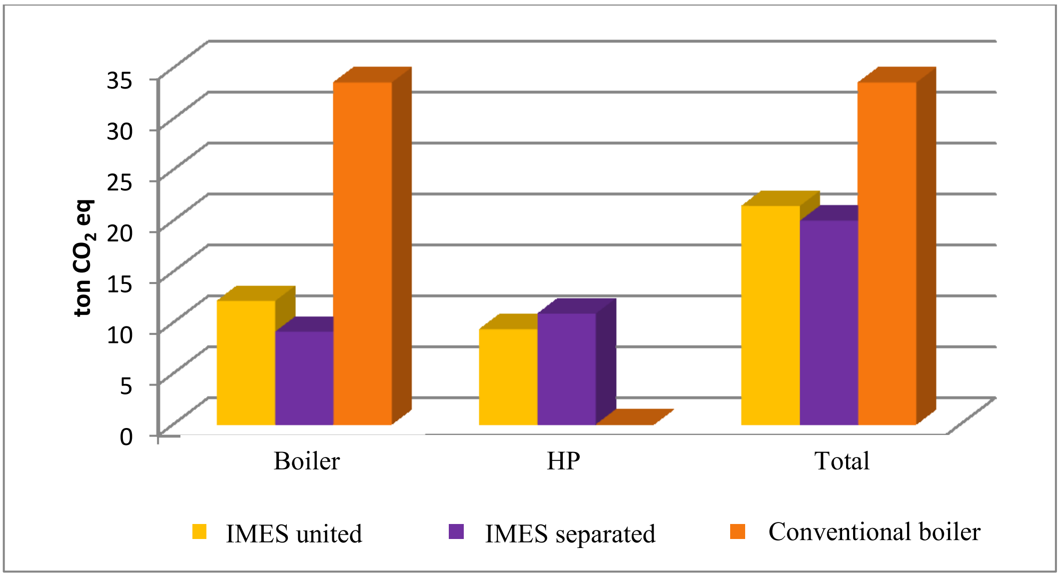


Figure 3. 18. Simulations results - CO_2 Emissions comparison

3.2 Phase 2. HVAC System modifications and optimization of the control system and integration of renewable energy

3.2.1 Changes to the IMES (Integrated Multi-Energy System)

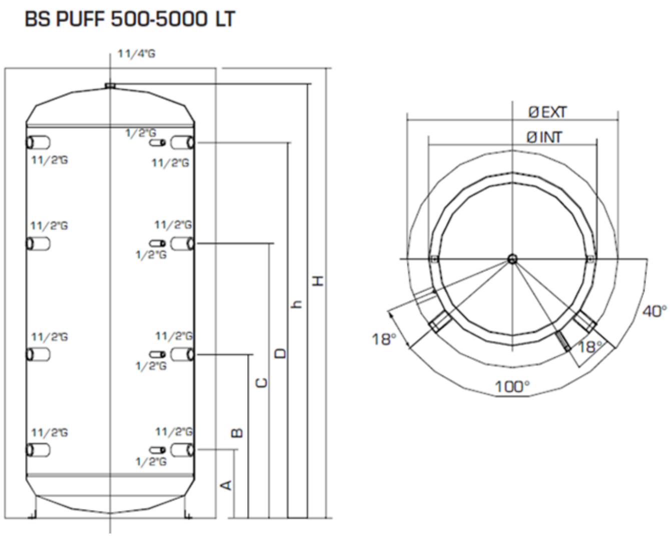
The second stage of research activity has been conceived on the basis of the results previously obtained . In particular, was greeted the remark emerged about the usefulness of the connection between the solar system and the heating generation section of the plant, on the basis of the small energy contribution provided. According to the partner company the connection has been removed, since its energy advantage was insignificant while the economic benefit related to the simplification of the system and the control logic were very interesting. Additional changes have affected other components of the system, especially according to the machine sizing and in relation at the type of solar collectors analyzed.

The initial solution of Phase 1 involved the use of 30 plane, glazed and with forced circulation, solar thermal collectors; each of them was characterized by a net absorber area of 2.30 m², with a maximum carrier fluid capacity of 2.12 liters and a design flow rate of 180 kg/h. The solar field was comprised of 5 arrays of 6 collectors connected in parallel. The panels were oriented to the South-West with a slope of 45° to the horizontal plane. In phase two, in addition to plane type of collectors, the performance of a field 18 of vacuum tube collectors, in arrays of 6 modules, has been evaluated. The technical features of the vacuum tube collectors are presented in Table 3. 39. Technical features of the solar vacuum tube collectors HP 20

Table 3. 39. Technical features of the solar vacuum tube collectors HP 20

Solar vacuum tubes collectors HP 20	
N. Tubes	20
Diameter of the tubes	65 mm
Material of tubes	borosilicate glass
Thickness of glass	1,7 mm
Length	2.000 m
Width	1.452 m
Height	0.165 m
Absorption coefficient	> 95%
Emission coefficient	< 5%
Gross area	2.904 m²
Aperture surface	2.270 m²
Absorption surface	1.984 m²
Empty weight	49.5 kg
Liquid content	0.9 l
Flow range	60 - 250 l/h
Design flow	160 l/h
Absorber element	copper reed
Length of the absorber	1730.0 mm
Width absorber	58.0 mm
Thickness of the absorber	0.15 mm
Selective coating	titanium oxide
Transport element	Copper / Heat pipe
Connection technology	ultrasonic welding
Maximum operating temperature	150°C
Maximum operating pressure	6 bar
Temperature maximum empty, form	245 °C
Maximum temperature in vacuum tubes	252 °C
Heat capacity	9.1 kJ/K
Heat capacity / sup. Absorber	4.6 kJ/(m2K)

The heat generator evaluated in the first stage was composed by three premixed condensation modules, with a useful power rate of 284.7 kW, and values of efficiency equal to efficiency of 98.2 % at the design load and 108% at 30% of partial load. At this stage of the analysis the component design power has been reduced to 220 kW, considering only two of the three modules originally planned. The heat pump, as previously, an air/water splitted machines, operating with refrigerant R410A, and like the as the boiler, its design power was reduced from 150 to 130 kW.The thermal storages intended for the DHW generations were maintained identical, while the tank dedicated to heating has been reduced in size up to a capacity of 800 liters, also was eliminated the immersed heat exchanger due to the elimination of the connection with the solar system. The technical description of the thermal storage model used in the analysis is provided in Figure 3.19 and Table 3.40. The final configuration of the IMES system is presented in Figure 3.20.



Item		Value
A	Junction/Probe/duct probe	260mm
B	Attack/Probe/duct probe	630 mm
C	Junction /Probe/duct probe	1030mm
D	Attack/probe/probe duct	1380 mm
E	Back exchanger	260mm
F	Flow heat exchanger	930 mm
h	Height without insulation	1620 mm
H	Height with insulation	1700 mm
ø est	tank with insulation	990 mm
ø int	tank without insulation	790 mm
ø thread		1 ½ “

Figure 3.19. DHW storage tank PUFFER 800

Table 3.40. Geometrical features of PUFFER 800

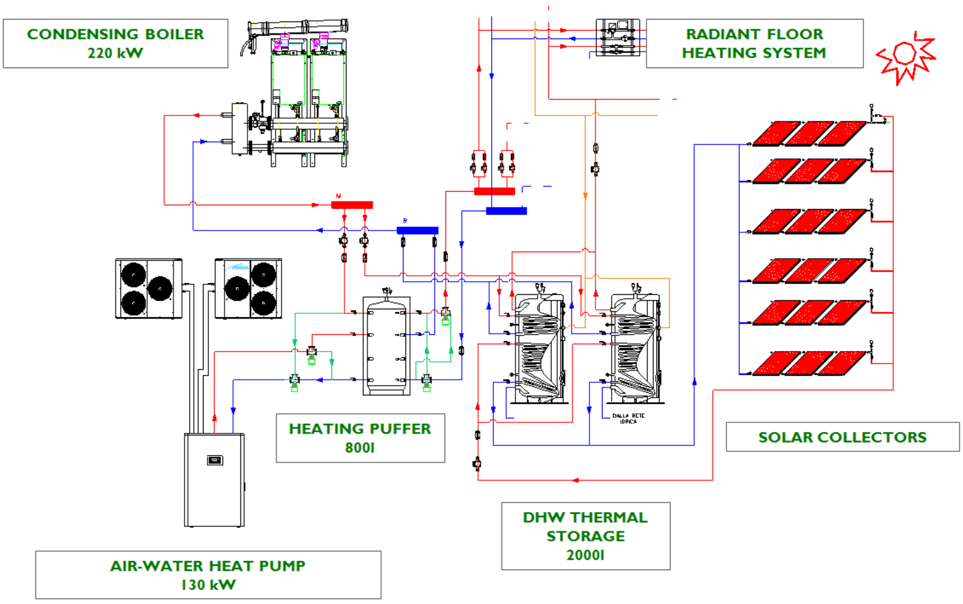


Figure 3.20. Plane of the HVAC system evaluated in the second stage (IMES).

3.2.2 Dynamic simulation for the performance analysis

3.2.2.1 Methods

This phase of the project has been dedicated to the comparison of the energy performance achieved by the IMES system compared to alternative system solutions.
The IMES described in the previous section was applied to the case study presented in the first chapter and was analyzed by comparing with two thermal plants of different design. The IMES solution will from now on referred to as solution 1, and the two comparison solutions will be respectively referred to as CASE 2 and CASE 3.

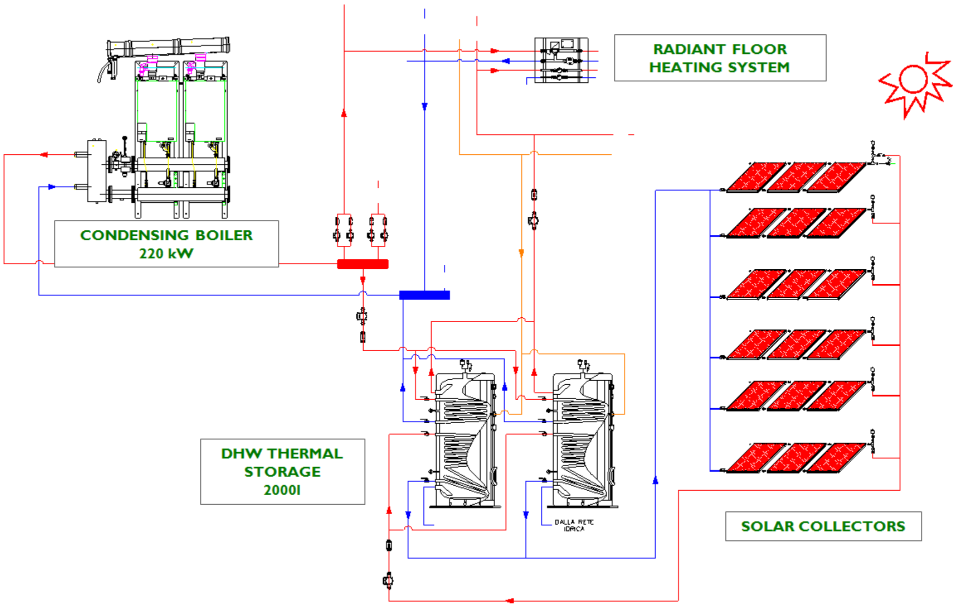


Figure 3.21. Plane of the HVAC system evaluated as CASE 2

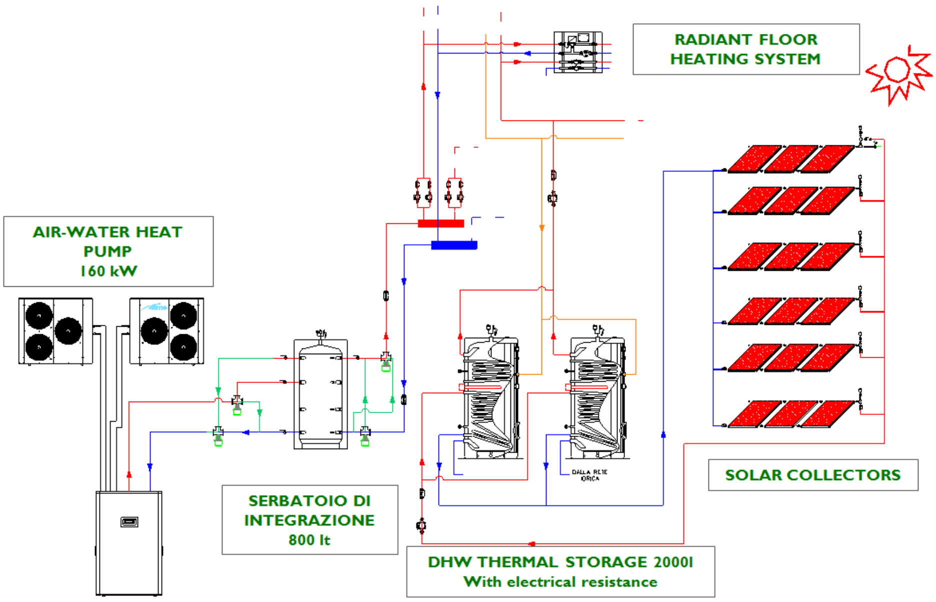


Figure 3.22. Plane of the HVAC system evaluated as CASE 3

The first considered comparison solution is presented in Figure 3.21. It is a conventional heat generation system composed by a traditional gas boiler combined with solar collectors, intended for the only production of DHW. Compared to the solution the storage tank of the heating system is absent. The tanks for the DHW generation displaced in parallel are connected the solar system for which both the solutions, plane glazed collectors and vacuum heat pipe, have been evaluated.
The second comparison solution, referred as CASE 3, is presented in Figure 3.22. In the analyzed configuration the heating energy demand is satisfy by the means of an air-water heat pump, designed for a power output equal to 160 kW. The DHW generation is supplied by the solar thermal system, integrated by an electrical heater capable of coping with DHW when the solar system is insufficient due to negative weather conditions.

3.2.2.2 Results

The Thermal Energy needs, according to the space heating and the generation of DHW, have already been presented in the first stage of the research, the same building been considered as case study. The heating Energy need is equal to 65950 kWh per year and the annual quote to DHW generation amounts to 34640 kWh. The results of the simulations carried out to assess the energy performance of the compared HVAS system are presented from Table 3.41 to Table 3.43

Table 3.41Energy performance of the IMES system..

			ENERGY OUTPUT	**ENERGY INPUT**	
			[kWh]	[kWh]	PE [tep]
HEATING	BOILER		39740	43715	3.76
	HP	(47%)	35240	10880	2.03
DHW	BOILER		5960	6550	0.56
	SOLAR	(86.21%)	37240	37240	0
TOTAL			118180		**6.36**
LOSSES[10]	16%				

Table 3.42. Energy performance of the CASE 2. Two types of solar collectors.

			ENERGY OUTPUT	**ENERGY INPUT**	
			[kWh]	[kWh]	PE [tep]
COLLETTORI SOLARI SOTTOVUOTO					
HEATING	BOILER		72571	78825	6.78
DHW	BOILER		5263	5800	0.50
	SOALR	(87.81%)	37926	37925	0
TOTAL			115760		**7.28**
LOSSES*	14%				
COLLETTORI SOLARI PIANI VETRATI					
HEATING	BOILER		68060	76014	6.54
DHW	BOILER		5645	5806	0.50
	SOALR	(87.21%)	38490	38490	0
TOTAL			112196		**7.04**
LOSSES[1]	10%				

[10] It considers the losses due to regulation, distribution, accumulation and emission

Table 3. 43. Energy performance of the CASE 3. Solar collectors, heat pump and electrical heater

			ENERGY OUTPUT	ENERGY INPUT	
			[kWh]	[kWh]	PE [tep]
HEATING	HP		71060	32660	6.11
DHW	ELECTRICAL HEATER		5235	5690	0.45
	SOLAR	(87,82%)	37740	37740	0
TOTAL			114040		**6.56**
LOSSES[1]	12%				

The results presented in the previous paragraph show how the CASE 1, labeled as IMES, compared to the other cases, requires the lower input of primary energy to satisfy the users thermal energy demand. The solution 1 is also able to cover more than 30% of the total energy supplied by renewable sources, while the solar system covers independently over the 86% energy requirements for DHW. These considerations show how the system fulfills the requirements introduced by recent legislation in thermal use of renewable energy in the residential sector [3]. A relevant fact is that the heat pump provides approximately the 47% of the energy needed to meet the thermal requirements for heating, and its average coefficient of performance during the year is equal to 3.05. This result is due to the particular control system of the IMES solution: the integration of multiple generation systems allows to activate in every condition the system more suitable and more efficient. The heat pump is therefore adjusted so that its activation is bound to the realization of a minimum instantaneous COP equal to 2.9. Below this threshold value the machine is turned off .

The comparison between the solutions analyzed also shows how the conventional system (boiler and solar collectors) , referred to as CASE 2, requires the higher primary energy input. This solution has been analyzed both according to the use of plane glazed solar collectors, both in the case of vacuum heat pipe. The simulations asset that, at least according to the contribution to the DHW energy supply, the two configuration of the solar field provide similar results, so the design choice has to be taken according to economical reasons.

The third solution, CASE 3, erased the boiler combining the operation of a heat pump and of the solar system, eventually integrated by an electrical heater in order to guarantee the satisfaction of the DHW demand. Results show how the solution has not to be underestimated from the point of view of the primary energy input, whether how questionable the integration via electrical resistance could be, while it is strongly penalized with regard to the cost of annual management. The considerations described above are graphically show in Figure 3. 23and in Figure 3.24.

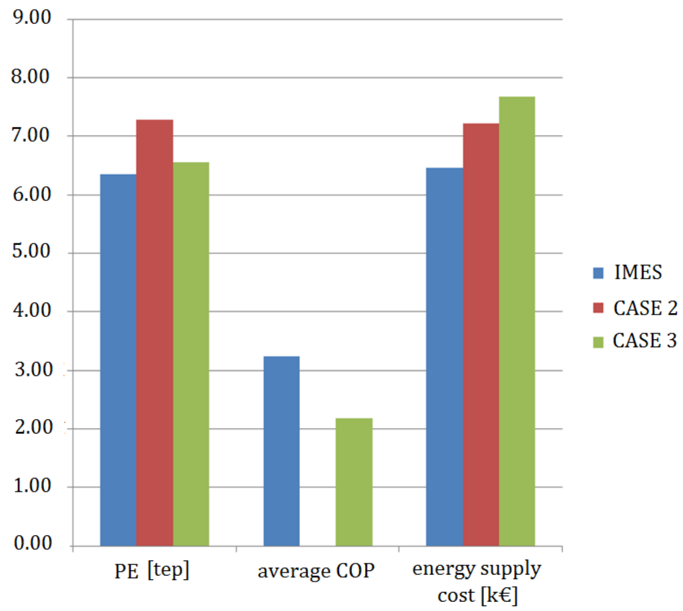


Figure 3. 23. Comparison of the energy performance of the analyzed solutions

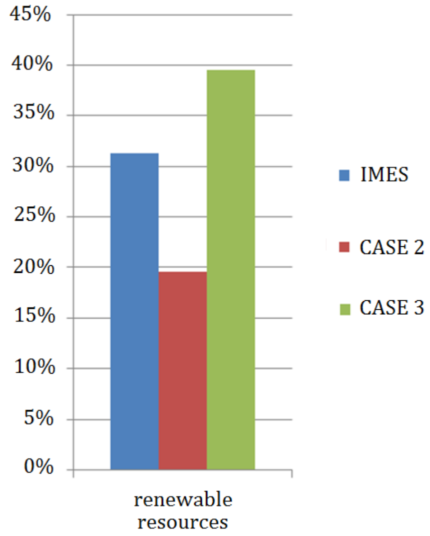


Figure 3.24. Comparison of the renewable energy share of the analyzed solutions

3.3 Phase 3. Evaluation of the performance of the integrated multi-energy system in not insulated buildings

3.3.1 Alternative Applications of the IMES system

The third phase of the project was designed to assess the possibility of extending the application field of the IMES systems. This system is designed to be applied to new buildings or buildings undergoing to a complete redevelopment, with well-insulated envelopes, characterized by low air permeability, doors and windows with good insulation and heating systems with radiant panels. These features allow to contain the energy needs and to serve the heating system with a moderate water flow temperature. These conditions are ideal for the application of systems IMES, where aerothermal source, fossil fuel and solar energy are involved.
In addition to the case study Furthermore described in the paragraph 3, which will be referred to as Solution A, other possible building scenarios were evaluated for installation of the integrated system, in particular, have been evaluated in the following cases :

• Solution B
This case considers a building subjected to a retrofit of the envelope but not of the thermal facilities, in which the traditional emission system operating with iron-cast radiators is maintained. This kind of solution presents limited heating needs, according to the insulation of the envelope, but the emission system requires a considerable flow temperature, not too compatible with the heat pump temperature range. The minimum flow temperature to the radiators has been set equal to 40°C, to meet the satisfaction of the heating requirements and the maximum allowed water flow rate according to the maximum pressure drops in the hydraulic circuits of the emission system. The heating system in this

case was analyzed in relation to a daily period of ignition of 14 hours as indicated in the Italian regulation [5]. Except for the emission system the configuration of the HVAC system is maintained the same as in the Solution 1.

• Solution C
This case considers a not insulated building modeled to be similar to the residential constructions built in Italy between the ‘60 and ‘70. In the simulation the flow temperature of the radiators sub-system was set to 50°C and two options for the extension of the ignition period have been evaluated: 14 and 20 hours per day.

3.3.1.1 Methods

The adaptation of the IMES described in the previous paragraphs to a radiators emission system has been realized through the creation of a model of the radiators by the means of an Excel spreadsheet. The model, on the basis of the supply water temperature, the indoor temperature and of the demand of heating energy at a given step of the simulation, established the size and the type of the evaluated radiators, is able to evaluate the energy performance of each radiator module and thus the carrier fluid flow required to meet the heating demand. The spreadsheet is implemented on the basis of the technical data of the radiating modules especially according to the limitations provided by the manufacturer for energy efficiency and the allowed pressure drop. The characteristics assumed for the radiators are presented in Table 3. 44, the model considered is the cast iron radiator LBT2/880. The performance of the radiators module in operating condition is shown in Table 3.45.
All the analyzed solutions consider a building with the same characteristics of the case study described in the first paragraph. The solution A and B, in particular, consider a building with external structures identical to the case study ones. The difference concerns only by the emission system, which in the first case is a radiant floor panel system, while in the second consists of cast iron radiators . The solution C refers to a building with a not isolated envelope. The building model was still built on the basis of the characteristics of the case study, to ensure a certain symmetry in the energy heating demands, making appropriate adjustments to downgrade the thermal insulation properties of the envelope. The building of the case study was, therefore , private of the insulation on the external structures, it has been equipped with frames thermally less performing and a higher air permeability value has been considered.
The result is a building which performances are equivalent to that of residential building built between the years 60 and 70 and not redeveloped, with a total heating requirement of 202380 kWh per year, corresponding to 97.30 kWh/m^{2}year , and an energy demand for the DHW generation about 35656 kWh per year equivalent to 17.14 kWh/m^{2}year .
The thermal characteristics and the stratigraphy of the building structures of the Solution C are presented in Table 3.46, Table 3.47 and Table 3.48.

Table 3. 44. Technical features of the modules of the radiators considered in Solutions B and C

SPECIFICHE TECNICHE

Modello	Dimensioni (mm)					Volume acqua per elemento litri	Peso (10 elementi) kg	Potenza termica nominale		Coefficiente caratteristico n
	Altezza H	Interasse mozzi I	Profondità P	Larghezza mozzo L	Posizione mozzo E			Watt	kcal/h	
Modello a 2 colonne										
LBT 2/880	880	800	70	60	35,0	0,52	50,7	78,6	67,6	1,324
Modello a 4 colonne										
LBT 4/580	580	500	146	60	73,0	0,71	62,7	94,5	81,3	1,318
LBT 4/680	680	600	146	60	73,0	0,83	71,7	108,0	92,9	1,325
LBT 4/880	880	800	146	60	73,0	0,99	92,7	135,0	116,1	1,358
Modello a 6 colonne										
LBT 6/430	430	350	225	60	112,5	0,81	74,7	105,0	90,3	1,372
LBT 6/580	580	500	225	60	112,5	0,99	97,7	123,0	105,8	1,378
LBT 6/680	680	600	225	60	112,5	1,16	110,7	135,0	116,1	1,382
LBT 6/880	880	800	225	60	112,5	1,43	136,7	192,0	165,1	1,354
Modello a 9 colonne										
LBT 9/300	300	220	340	60	170,0	0,95	80,7	111,0	95,5	1,362

Le rese, secondo UNI EN 442 hanno i seguenti valori di calcolo: T entrata = 75° C - T uscita = 65° C - T media = 70° C - T ambiente = 20° C - Δt = 50° C

Table 3. 45. Energy performance of a module of the radiators considered in Solutions B and C

POTENZA TERMICA A Δt DIVERSI DA 50 °C

Δt (° C)	LBT 2/880 (W)	LBT 4/580 (W)	LBT 4/680 (W)	LBT 4/880 (W)	LBT 6/430 (W)	LBT 6/580 (W)	LBT 6/680 (W)	LBT 6/880 (W)	LBT 9/300 (W)
30	40,0	48,2	54,9	67,5	52,1	60,9	66,7	96,1	55,4
32	43,5	52,5	59,8	73,6	56,9	66,5	72,9	104,9	60,4
34	47,2	56,9	64,8	80,0	61,9	72,3	79,2	113,9	65,6
36	50,9	61,3	69,9	86,4	66,9	78,2	85,8	123,1	71,0
38	54,7	65,8	75,1	93,0	72,1	84,3	92,4	132,4	76,4
40	58,5	70,4	80,4	99,7	77,3	90,5	99,2	141,9	81,9
42	62,4	75,1	85,7	106,5	82,7	96,7	106,1	151,6	87,5
44	66,4	79,9	91,2	113,5	88,1	103,1	113,1	161,5	93,3
46	70,4	84,7	96,7	120,5	93,7	109,7	120,3	171,5	99,1
48	74,5	89,6	102,3	127,7	99,3	116,3	127,6	181,7	105,0
50	**78,6**	**94,5**	**108,0**	**135,0**	**105,0**	**123,0**	**135,0**	**192,0**	**111,0**

Equazione caratteristica per il calcolo della potenza a Δt diversi da 50ºC, $Q = Qn*(\Delta t/50)^n$, dove: Qn = Resa termica a Δt 50° C - Δt = Delta richiesto - n = Coefficiente caratteristico

Table 3.46. External walls features of the not insulated envelope of the Solution C

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0.130
Lime mortar or lime concrete	1800	1.5	0.9	0.020
Poroton 30 cm	800	30	0.276	1.090
Liminal outer layer				0.040
Total		42		4.080
U-Value	**1,987 [W/m²K]**			

Table 3.47. Basement floor features of the not insulated envelope of the Solution C

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0.170
Ceramic tiles	2300	1.5	1	0.020
lean concrete base	2200	6	0.93	0,060
Block attic 2.1.03i / 2240	1214	24	0.727	0,330
Lime mortar or lime concrete	1800	1	0.9	0,010
Liminal outer layer				0,170
Total		46		2,590
U-Value	**1,693 [W/m²K]**			

Table 3.48. External roof features of the not insulated envelope of the Solution 3

Description	D	s	λ	r
Ambient air				
Liminal inner layer				0.170
Ceramic tiles	2300	1.5	1	0.020
lean concrete base	2200	6	0.93	0.060
ordinary concrete	2200	5	1.28	0.040
Panel Predalles 4-16-4	1200	24	0.354	0.680
Liminal outer layer				0.170
Total		36.5		3.530
U-Value	**1.035 [W/m²K]**			

3.3.1.2 Results

The results of the simulations carried out on the three solutions of system, considered to meet the thermal requirements described in the previous section, are shown in Table 3.49, Table 3.50 and Table 3.51.
The Table 3.49 shows the results of the simulation A, they are very similar to those obtained for the case 1 of the previous chapter, in fact it is the same plant configuration applied to the same building: the only changes have affected the regulation system and some simulation parameters, like as the calculation accuracy.

Table 3.49. Simulation results - Solution A

ENERGY NEED	**HEATING**	**DHW**	**TOTAL**
[kWh,t]	62'530	35'656	98'186

		ENERGY SUPPLY [kWh,t]		**ENERGY INPUT [kWh]**	**[tep]**
HEATING	HP (COP =3,17)	31'492	42.0%	10'431	1.95
	BOILER	43'488		47'837	4.11
ACS	BOILER	6'266		6'892	0.59
	SOLAR COLLECTORS	33'872	84.0%	33'872	-
TANK LOSSES	PUFFER	1'058			
	DHW 2S X2	3'743			
TOTAL		115'118			**6.66**

Table 3.50. Simulation results - Solution B

ENERGY NEED	**HEATING**	**DHW**	**TOTAL**
[kWh,t]	66'872	35'656	98'186

		ENERGY SUPPLY **[kWh,t]**		**ENERGY INPUT** **[kWh]**	**[tep]**
HEATING	HP (COP =3.12)	425	-	143	0.03
	BOILER	68'550		75'405	6.48
ACS	BOILER	6'943		7'637	0.66
	SOLAR COLLECTORS	33'195	82.7%	33'872	-
TANK LOSSESS	PUFFER	1'104			
	DHW 2S X2	2'291			
TOTAL		109'113			**7.17**

Table 3.51. Simulation results - Solution C

ENERGY NEED	**HEATING**	**DHW**	**TOTAL**
[kWh,t]	202'381	35'656	238'037

		ENERGY SUPPLY **[kWh.t]**		**ENERGY INPUT** **[kWh]**	**[tep]**
HEATING	HP (COP =3.05)	2'136	-	740	0.14
	BOILER	242'416		266'657	22.93
ACS	BOILER	7'607		8'368	0.72
	SOLAR COLLECTORS	32'531	0.81%	33'872	-
TANK LOSSES	PUFFER	1'058			
	DHW 2S X2	4'372			
TOTAL		284'690			**23.79**

The Table 3.50 shows the results of the solution B. It is characterized by the IMES system applied to an insulated building in which as emissions devices cast iron radiators are installed.
In this configuration, the need to maintain a sufficient flow temperature for the radiator system, and their limited exchange surface respect to a radiant floor, of impose rather relevant water flows to guarantee the satisfaction of the users heating demand. This implies that, in spite of the fact that the flow temperature tried to be contained (it is maintained between 55 and 40 °C) the storage tanks reach a temperature level that affected by the contribution of the heat pump, making it almost irrelevant.
The Table 3.51 shows the results of the solution C. It is a system IMES applied to a not insulated building equipped with a radiators emission system. In this case, like in the previous one, the performance is strongly influenced by the flow temperature of the heating system, which affected the average temperature inside the heating storage and then the ignition of the heat pump. Also in this case the heat pump is rarely called into operation .

3.4 Conclusions

The results showed proves how the IMES solution is not particularly suitable for installation in facilities provided with radiators as emission devices. In such cases the synergy between the various energy sources, which is the basis of philosophy of IMES, fails. The evaluated heat pump, in fact , is not suitable for applications at temperatures above 45 °C, therefore, fails to contribute to the heating thermal generation. Furthermore, the choices of a smaller size puffer respect to the configuration analyzed in the paragraph 3.1 (800l versus 2000l) makes harder the formation of a real stratification inside the tank. These considerations are valid both in the case of an insulated building envelope and even more in the case of an not insulated one, because, even with adjustment of the emission system according to the number of radiators and the total power output, it requires a greater water flow rate that accentuate the mixing inside the puffer.

It is confirmed the advantage introduced by the integration of the condensing generator with the solar system for the DHW generation. In both the Solutions B and C, the system covers over 50% of the energy requirements, satisfying Italian regulation demand [3] allowing a reduction of primary energy requirement of approximately 30% compared to a solution without solar system.

Some possible interventions to increase the advantage of a IMES system in the evaluated applications:

- a certain advantage could derive by the increase of the heating storage volume (puffer) , so as to increase the natural stratification and then allow the heat pump to operate in the better conditions;
- another possibility consists in the replacement of the heat pump with a machine operating with refrigerant gas able to achieve higher temperatures;
- finally, the performance of an emission system equipped with fan coils could be evaluated considering that they allow a lower operating temperature.

3.5 References

[1] TRNSYS Manual - © 2006 by the Solar Energy Laboratory, University of Wisconsin-Madison

[2] TRY Europe WMO Region 6- World Meteorological Organization Region and Country

[3] Decreto Legislativo 3 marzo 2011 , n. 28 Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE.

[4] Produzione di acqua calda ad accumulo: il pericolo legionella - IDRAULICA -pubblicazione periodica di informazione tecnico-professionale. 01/1999 n16- CALEFFI

[5] Decreto Legislativo 30 maggio 2008 , n. 115. Attuazione della direttiva 2006/32/CE relativa all'efficienza degli usi finali dell'energia e i servizi energetici e abrogazione della direttiva 93/76/CEE

[6] Decisione Della Commissione del 18 luglio 2007 che istituisce le linee guida per il monitoraggio e la comunicazione delle emissioni di gas a effetto serra ai sensi della direttiva 2003/87/CE del Parlamento europeo e del Consiglio

CHAPTER

4

EVALUATIONS FOR THE RETROFIT OF THE EUROPEAN RESIDENTIAL BUILDING STOCK

CHANGES ON THE ENVELOPE AND ON THE CONDITIONING SYSTEMS FOR ACHIEVING THE TARGET OF A LOW ENERGY BUILDING.

Abstract

The renovation of the existing building stock and the improvement of the energy performances are expected to have a key role in the increasing of European energy efficiency.

This chapter presents an analysis on the possibilities of energy saving according to the retrofit of the European building stock. The work has considered the composition of the dwellings around Europe, identifying a general classification of the existent buildings. The analysis has been conducted on the basis of four case studies: a single dwelling house, a linear terraced house, and two multifamily buildings, respectively with low and high housing density. For each case study an energy performance analysis has been carried out on the status before and after a major renovation of the building envelope and of the HVAC system. Several actions have been considered both according to the retrofit of the envelope both considering the design of the HVAC system meant to replace the conventional het generator systems. According to the building renovation five solutions have been identify and analyzed in order to achieve the minimum energy needs according to heating and cooling. The optimum solution, according to the energy demand and the cost of the retrofit, has been applied to four different HVAC system configuration in order to supply the total thermal energy required by the users with the minimum input of primary energy. The energy performance have been evaluated by the means of dynamic simulation carried out with the commercial software TRNSYS. In the chapter a description of the methodology followed in the work is presented, as well as the parameters and the technical features of the building structures and of the components modeled into the HVAC system. The work aims to evaluate the possible energy savings due to the renovation of the buildings into low energy buildings, to achieve this goal 20 simulation have been carried out on the building model of the case study, and 80 simulations have been needed to conclude the analysis on the performance of the HVAC system. Four cities have been considered in the study to assess the effects of the redevelopment in different European climate conditions: Budapest, Venice, Athens and Helsinki.

4.1 Introduction

One of the primary European Union's "Europe 2020" energy strategy is the reduction of the total energy consumption by the means of energy efficiency improvements. It is widely known that in European Union (EU) the building sector is responsible of about the 40% of the total final energy consumption, and that the 36% of the Europe global CO_2 emissions are imputable to existing buildings. During the last decade the European Commission released the first legislative instrument aimed to improve the energy performance of buildings: the "Energy Performance of Building Directive (EPBD) was introduced in the 2002 and updated in the 2010 [1,2]. The last version sets that all new buildings should be "nearly-zero" energy.

With this work authors want to face the issue of the actual European building stock. According to the fact that, even if the energy demands of the future buildings will be very low, the increase in energy demand will only be reduced, because its greater share is due to existing buildings. It is evident that the largest energy-saving potential lies on existing buildings, which trough major renovation or a simpler retrofitting could largely reduce their energy demands as far as it is technically and economically feasible.

The renovation of the existing building stock and the improvement of the energy performances are expected to have a key role in the increasing of European energy efficiency.

The average annual rate for the construction of new dwelling within the EU-15 member states is about 1% and the replace rate is the 0,07% of the existing stock [3]. The esteems sets that only the 25% of the buildings that will exist in the 2050 haven't already to be built, that means that the 75% of the future build stock is currently existing.

Dwellings represent about the 75% of the European building stock. Single-families houses account for 64% and multi-storey family buildings for the 36%. These are the most representative European buildings, and is likely the new buildings will follow the same topology [6].

This work aims to evaluate the possible energy savings due to the renovation of the residential building stock into low energy buildings.

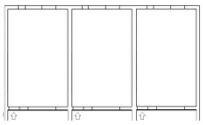
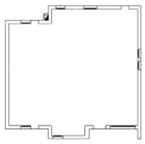
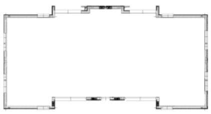
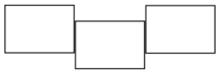
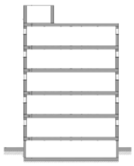
The work could be divided into three stages. The first phase aims to analyze the European building stock and to classify the existent buildings into macro categories. During the second phase for each category, previously identify, a case study has been implemented and analyzed in order to asset the energy demand for heating, cooling, and DHW generation. After the evaluation of the current conditions the third phase will evaluate the energy effects of a major renovation of the case study. There are several possible actions for a total retrofit of the building envelope and of the HVAC plant. The aim of the project is to propose a feasible tool to deal with the issue of the energy efficiency of the residential building sector, trying to ease the transformation from current building stock to low energy buildings.

The analysis has been conducted on the basis of four case studies: a single dwelling house, a linear terraced house, and two multifamily buildings, respectively with low and high housing density.

4.2 Case Studies: modelization and energy demand analysis.

The first part of the research has been spent in the collection of data and information on activities related to the proposed study. Particular attention was paid on journals and conference proceedings concerning the buildings stock definitions and the possible retrofits of buildings [4,5].
Four building categories have been selected as a representative sample of the residential building stock around Europe, and for each one parameters affecting the heating and cooling energy demands, as well as for the domestic hot water (DHW) energy demand, have been evaluated.
The work shows the analysis on few the case studies conducted in order to determine the heating energy demands due to the building envelope, before and after its major renovation. The cases are presented in Table 4.5; they are four types of residential building, two of them are single family houses other two are multifamily buildings.

Table 4.5. Resume of the case studies analyzed in the paper as sample of the actual residential building stock in needing of a major renovation.

	Case 1	Case 2	Case 3	Case 4
External view				
Plan				
Section				
S/V ratio	0.9	0.84	0.39	0.46
Number of storeys	4	2	6	6

Each case has been modelled with the commercial code TRNSYS. The envelopes have been detailed implemented according to the real physical and thermal property of the external and internal walls, roofs, floors, and windows. For each case study the list of the opaque and glazed structures will be given afterwards in the paper. Regarding to windows, standard property have been chosen for each of the considered types. Between before and after the building renovations windows characteristics have been improved as is show in
Table 4.6.
In order to find the optimum solution according to the building redevelopment, several thickness of insulation have been considered during the analysis. The effect on the thermal behaviour of the buildings of insulation thickness of about 6, 8, and 10 cm have been studied. Different kinds of windows have been modelled as well. The multifamily buildings model before renovation have been

implemented with single glass windows and wood frame with an area of about the 15% of the total surface. The single house and the terraced house have been equipped with a double glass windows with a overall U-value of about 2.8 W/m^{2}K. After the renovation all model have been implemented with double glass windows with argon gas inside the chamber, with a overall U-value of 1.4 W/m^{2}K.
Occupancy scheduling have been created in order to account internal gains due to people and lighting systems, they have been divided between single and collective houses, Table 4.7 and Table 4.8.
The given schedulings have to be multiply by the number of family members, and the internal gain due to people have been considered on the basis of the standard ISO 7730. As regarding of the values given for lighting, they are referred to the total illuminated area with a heat emission of 5 W/m^2. Air Infiltrations and the effect of the natural ventilation on the heating and cooling energy demand have been evaluated as well, considering in the model an average value of air infiltration equal to 0,3 V/h.
Weather conditions, such as external temperature, relative humidity, solar radiation on the building envelope have been accounted by the software, on the basis of standard TRY (Test Reference Year) database. Simulations have been carried out according to different climates to assess the effects of the redevelopment in different European cities: Budapest, Venice, Athens and Helsinki,

Table 4.6. Property of the windows before and after the building renovation.

WINDOWS PROPERTY	**BEFORE**		**AFTER**	
	U-VALUE [W/m^{2}K]	g-factor	U-VALUE [W/m^{2}K]	g-factor
CASE 1 and 2	5.8	0.855	2.8 and 1.4	0.755 and 0.589
CASE 3 and 4	5.8	0.855	2.8 and 1.4	0.755 and 0.589
Ramen 15%, U=2.27 W/mK				

Table 4.7. Occupancy scheduling used to asset the heating energy demand

OCCUPANCY SCHEDULINGS			
Time	SINGLE HOUSING		COLLECTIVE HOUSING
	day	night	day+night
0.00 – 7.00	0	1	1
7.00 – 8.00	1	0,5	1
8.00 – 9.00	0,5	0	0,5
9.00 – 16.00	0,12	0	0,12
16.00 – 19.00	0,5	0	0,5
19.00 – 20.00	1	0	1
20.00 – 22.00	0,5	0,5	1
22.00 – 24.00	0	1	1

Table 4.8. Lighting scheduling used to asset the heating energy demand

LIGHTING SCHEDULINGS			
Time	SINGLE HOUSING		COLLECTIVE HOUSING
	day	night	day+night
0.00 – 7.00	0	0	0
7.00 – 8.00	0,5	0,5	1
8.00 – 9.00	1	0	1
9.00 – 16.00	0	0	0
16.00 – 19.00	0,5	0	0,5
19.00 – 20.00	0,5	0	1
20.00 – 22.00	0,5	0,5	1
22.00 – 24.00	0	0	0

4.3 Detailed description of each case study.

4.3.1 CASE 1

The Case 1 is a terraced house, and for the matters of this work a single dwelling has been considered. It is a four storey house, oriented with the front at the South and the back at the North. Eastern and Western walls are boundary with the adjacent buildings. The dwelling consists in an unheated underground floor, which contains the garage, the thermal power plant of the house and another large room; an heated ground floor, which contains the living area of the dwelling, and an heated first floor meant to be the sleeping area. Another room has been realized in the not heated garret. The total thermal regulated area is about 126 m^2.

Table 4.9 shows the property of the main walls of the building before and after its major renovation. Front and back convective heat transfer coefficient and the U-value are presented as well as a brief description of the layers of the wall. To complete the specification of the data for the simulation the Table 4.10 shows a resume of the thermal and physical properties of the wall layers.

Table 4.9. Description of the walls used in the model of the case 1

BEFORE RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m^{2}K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m^{2}K]**
ESTERNAL WALL			
plaster 0,015, hollow brick 0,08, air layer 0,04, concrete block 0.155, gypsum lime plaster 0,015	0.11 - 0.64	0.305	0.96
BASEMENT			
tile 0.015, lean cement mortar 0.05, sand gravel concrete 0.4, pebbles 0.3	0.11 – 0.11	0.765	1.011
ROOF			
sand-lime plaster internal use 0.015, floor slab_24 0.24, lean cement mortar 0.05, roof tiles 0.015	0.11 - 0.64	0.32	1.74
AFTER RENOVATION			
LAYERS [m]	FRONT – BACK h [J/h m^{2}K]	WALL THICKNESS [m]	U-VALUE [W/m^{2}K]
ESTERNAL WALL			
plaster 0,015, hollow brick 0,08, air layer 0,04, concrete block 0.155, polistirene 036 0.1, gypsum lime plaster 0,015	0.11 - 0.64	0.405	0.26
BASEMENT			
tile 0.015, lean cement mortar 0.05, polistirene 036 o.1, sand gravel concrete 0.4, pebbles 0.3	0.11 – 0.11	0.865	0.577
ROOF			
sand-lime plaster internal use 0.015, floor slab_24 0.24, polistirene 036 0,1, lean cement mortar 0.05, roof tiles 0.015	0.11 - 0.64	0.42	0.3

Table 4.10. Physical and thermal property of the layer of the opaque structures of the case

LAYER	**CONDUCTIVITY [W/m^{2}K]**	**CAPACITY [kJ/kgK]**	**DENSITY [kg/m^3]**
plaster	0.900	0.84	1700
hollow brick	0.300	0.84	700

sand-lime plaster internal use	0.900	0.91	1800
sand-lime plaster external use	1.400	0.67	2000
air layer	RESISTANCE [m^2K/W]	0.18	
gypsum lime plaster	0.700	1.01	1400
sand gravel concrete	1.160	0.67	2000
polical polistirene concrete	0.135	1	500
floor slab_24	0.722	0.92	1214
polistirene 036	0.036	1.1	30
concrete block	0.500	0.84	1400
tile	1.200	1	2300
lean cement mortar	1.500	0.67	1800
pebbles	0.700	0.67	1800
roof tiles	1.000	1	1800

4.3.2 CASE 2

The Case 2 is a detached two storeys house. The ground floor is divided among a living area, that contains a laundry a cellar and a bathroom, and two other areas used as garage and thermal power plant site. The first floor contains both the living and the sleeping area; there are a kitchen, a living room a bathroom and three bedrooms. The heated total area is about 210 m^2. Table 4.11 and
Table 4.12 4.12 show the property of the main walls of the building before and after its major renovation and a resume of the wall layer properties.

Table 4.11. Description of the walls used in the model of the case 2

BEFORE RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m^2K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m^2K]**
ESTERNAL WALL			
cement mortar 0.03, hollow brick 1200 0.25, cement mortar 0.03, smoothing cement 0.01, plaster 0.01	0.11 - 0.64	0.31	1.41
BASEMENT			
tile 0.013, lightweight concrete 0.1, concrete 0.05, pebbles 0.086	0.11 – 0.11	0.30	0.79
ROOF			
roof hollow brick 0.12, concrete 0.04, bitumen 0.01, roof tiles 0.02	0.11 - 0.64	0.185	1.98
AFTER RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m^2K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m^2K]**
ESTERNAL WALL			
cement mortar 0.03, hollow brick 1200 0.25, cement mortar 0.03, eps polistirene 0.12, smoothing cement 0.01, plaster 0.01	0.11 - 0.64	0.43	0.27
BASEMENT			
tile 0.013, lightweight concrete 0.1, xps polistirene 0.05, concrete 0.05, pebbles 0.086	0.11 – 0.11	0.35	0.79
ROOF			
roof hollow brick 0.12, concrete 0.04, xps polistirene 0.04, bitumen 0.01, roof tiles 0.02	0.11 - 0.64	0.23	0.61

Table 4.12. Physical and thermal property of the layer of the opaque structures of the case 2

LAYER	**CONDUCTIVITY [W/m^{2}K]**	**CAPACITY [kJ/kgK]**	**DENSITY [kg/m^3]**
pebbles	0.70	0.67	1'800
roof tiles	1.00	1.00	1'800
plaster	0.90	0.84	1'700
hollow brick 1200	0.53	0.92	1'188
cement mortar	0.90	0.91	1'800
concrete	1.28	0.88	2'200
smoothing cement	0.51	0.86	1'650
lightweight concrete	0.15	0.92	500
bitumen	0.17	0.92	1'200
roof hollow brick	0.42	0.92	617
xps polistirene	0.03	0.92	50
eps polistirene	0.04	1.25	30

4.3.3 CASE 3

The case 3 is the first one of the two analyzed collective residential buildings. Although the solutions can appear similar, actually they present few important differences.

Case 3 is a stand-alone five storeys building, with 4 apartments on each floor, for a net living area of 1335 m^2. The apartments have an identical design: they consist in a open space kitchen/living room, in two bedroom and one bathroom, for a net heated area of 67 m^2 . The building also contains a basement used as garage and thermal power plant location. Table 4.13 and

Table 4.14 show the property of the main walls of the building before and after its major renovation and a resume of the wall layer properties.

Table 4.13. Description of the walls used in the model of the case 3

BEFORE RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m^{2}K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m^{2}K]**
ESTERNAL WALL			
cement mortar 0.015, hollow brick 30 0.3, smoothing cement 0.005, sand-lime plaster external use 0.015	0.11 - 0.64	0.335	0.775
BASEMENT			
tile 0.013, lean concrete 0.035, concrete 0.24, predales 4/16/4 0.24	0.11 – 0.11	0.528	0.76
ROOF			
cement mortar 0.015, floor slab_24 0.29, bitumen 0.01, concrete 0.1, roof tiles 0.015	0.11 - 0.64	0.43	1.25
AFTER RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m^{2}K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m^{2}K]**
ESTERNAL WALL			
cement mortar 0.015, hollow brick 30 0.3, polistirene 036 0.1, smoothing cement 0.005, sand-lime plaster external use 0.015	0.11 - 0.64	0.435	0.27
BASEMENT			
tile 0.013, lean concrete 0.035, polistirene 036	0.11 – 0.11	0.558	0.37

0.03, concrete 0.24, predales 4/16/4 0.24			
ROOF			
cement mortar 0.015, floor slab_24 0.29, polistirene 036 0.1, bitumen 0.01, concrete 0.1, roof tiles 0.015	0.11 - 0.64	0.53	0.29

Table 4.14. Physical and thermal property of the layer of the opaque structures of the case 3

LAYER	CONDUCTIVITY [W/m^{2}K]	CAPACITY [kJ/kgK]	DENSITY [kg/m^3]
roof tiles	1.000	1	1800
plaster	0.900	0.84	1700
cement mortar	0.900	0.91	1800
concrete	1.280	0.88	2200
bitumen	0.169	0.92	1200
plaster	0.900	0.84	1700
sand-lime plaster external use	1.400	0.67	2000
floor slab_24	0.722	0.92	1214
polistirene 036	0.036	1.1	30
concrete block	0.500	0.84	1400
tile	1.200	1	2300
lean cement mortar	1.500	0.67	1800
roof tiles	1.000	1	1800
predales 4/16/4	0.354	1.2	1200
hollow brick 30	0.276	0.92	800
lean concrete	0.930	0.88	2200

4.3.4 CASE 4

The fourth analyzed case is a typical “plattenbau” building. A Plattenbau is a building whose structure is made of large, prefabricated concrete slabs. Although Plattenbauten are often considered to be typical of “East Germany”, the prefabricated construction method was used extensively also elsewhere, particularly in public housing. The Plattenbauten building method is also called large-panel system building (LPS).

For distinguishing the two types of collective buildings analyzed, the authors have used a classification based on the housing density. Building designed as the case 4 are often placed one next to another, in line or in a quadrangular form. This means that in comparison with the stand-alone building of the case 3 they can be associated to a higher house density. So the case 3 is named as low density multifamily building, while the case 4 is labeled as high density multifamily building.

The case 4 is a five storey building plus a basement, it is oriented with the front at the South and the back at the North. Eastern and Western walls are boundary with the adjacent buildings. It has two apartments for each floor with a net heated area of 68.5 m^2, for a total dwelling area of about 681 m^2. Each apartment is made by 6 rooms and it can accommodate up to 4 people.

Table 4.15 and Table 4.16 show the property of the main walls of the building before and after its major renovation and a resume of the wall layer properties.

Table 4.15. Description of the walls used in the model of the case 4

BEFORE RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m²K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m²K]**
ESTERNAL WALL			
gypsum lime plaster 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1	0.11 - 0.64	0.265	1.38
BASEMENT			
ceramics 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1, bitumen 0.01	0.11 – 0.11	0.275	1.33
ROOF			
gypsum lime plaster 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1, bitumen 0.06	0.11 - 0.64	0.325	0.92
AFTER RENOVATION			
LAYERS [m]	**FRONT – BACK h [J/h m²K]**	**WALL THICKNESS [m]**	**U-VALUE [W/m²K]**
ESTERNAL WALL			
gypsum lime plaster 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1, polistirene 036 0.1, gypsum lime plaster 0.015	0.11 - 0.64	0.365	0.3
BASEMENT			
ceramics 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1, bitumen 0.01	0.11 – 0.11	0.275	1.33
ROOF			
gypsum lime plaster 0.015, concrete slab 0.1, wooden wool 0.05, concrete slab 0.1, polistirene 0360.1, bitumen 0.06	0.11 - 0.64	0.63	0.274

Table 4.16. Physical and thermal property of the layer of the opaque structures of the case 4

LAYER	**CONDUCTIVITY [W/m²K]**	**CAPACITY [kJ/kgK]**	**DENSITY [kg/m³]**
bitumen	0.169	1	1100
gypsum lime plaster	0.350	1	1200
wooden wool	0.150	0.015	570
ceramics	1.200	1	2000
concrete slab	1.130	1	1400
polistirene 036	0.036	1.1	30

4.4 Energy demand analysis before an after the renovation of the buildings envelope

The yearly energy demands of each case study have been analyzed by the means of a dynamic simulation. The comparison between the results obtained before and after the building renovation allows to evaluate the energy saving amount due to the improvement of the envelope.
The following tables and charts will show the result of the analysis carried out on the basis of the measures chose for the renovation of the envelope for each place evaluated, that means for each of the climate considered.

For the retrofitting of the building envelope several measures have been considered and even combined to guarantee the maximum reduction of the energy demand. According to the building redevelopment, several thickness of insulation have been considered. The effect of slabs of polystyrene with thickness of 6, 8, and 10 cm have been studied. Different kinds of windows have been modelled as well. The Table 4.17 resumes the measures considered for the redevelopment of each case study.

Table 4.17. Retrofitting measures

BUILDING REDEVELOPMENT – RETROFITTING ACTIONS		
ACTION 0	ANTE W56	None action is considered – pre-retrofit state No insulation and single glazed windows (U-value 5.6 [W/m^{2}K]; g-factor 0.855)
ACTION 1	ANTE W28	None building insulation, replacement of windows with double glazed windows (U-value 2.8 [W/m^{2}K]; g-factor 0.755)
ACTION 2	ANTE W14	None building insulation, replacement of windows with double glazed windows (U-value 1.4 [W/m^{2}K]; g-factor 0.589)
ACTION 3	RETROFIT 6noW	Building envelope insulation with 6 cm of polystyrene (0.036 W/m^{2}K). Single glazed windows (U-value 5.6 [W/m^{2}K]; g-factor 0.855)
ACTION 4	RETROFIT 6	Building envelope insulation with 6 cm of polystyrene (0.036 W/m^{2}K). Replacement of windows with double glazed windows (U-value 1.4 [W/m^{2}K]; g-factor 0.589)
ACTION 5	RETROFIT 8	Building envelope insulation with 8 cm of polystyrene (0.036 W/m^{2}K). Replacement of windows with double glazed windows (U-value 1.4 [W/m^{2}K]; g-factor 0.589)
ACTION 6	RETROFIT 10	Building envelope insulation with 10 cm of polystyrene (0.036 W/m^{2}K). Replacement of windows with double glazed windows (U-value 1.4 [W/m^{2}K]; g-factor 0.589)

4.4.1 BUDAPEST – Continental climate

4.4.1.1 CASE 1

The Table 4.18 presents the results of the renovation fort the case study number 1, the terraced house, in the weather conditions of Budapest. This city has been considered as example for the European continental climate. The table shows in a very condensed way many important results. Each column presents the yearly and monthly energy demand according status of the building. The first status presented the base case that means building envelope before the renovation, with not insulated opaque structures and single glazed windows (action 0). The second and the thirds columns represent the building with a not insulated envelope but with better kinds of windows, respectively double glazed windows with a global U-value of 2.8 and double gazed windows equipped with argon gas into the chamber in order to obtain a U-value of 1.4 W/m^{2}K (action 1 and action 2). The fourth columns represent an insulated building, with a thickness of 6 cm of polystyrene 0360, but no improvements according to windows that are single glazed (action 3). The last three columns shows the results of the building insulated respectively with 6,8,10 cm of polystyrene 0360, and equipped with the best type of windows, the ones with the lower U-value (actions 4, 5 and 6).
Each column presents two sets of data, the one on the left show the value in winter conditions, according to heating season and the one on the right shows the value according to cooling conditions.

To allow a comparison of the effect of the building renovation on the only basis of the external climate and of the chosen action for each case study, heating and cooling season have not been considered as regulated by national laws. The analysis have been carried out accounting the energy demands needed by the case studies to maintain a minimum temperature of 20°C and a maximum temperature of 26°C in every climate.
The line that presents the overall energy demand during the year, shows also the percentage value of the heating energy demand of each solution compared to the situation before renovation.

Table 4.18. CASE 1- Energy demands before and after renovation in Budapest weather conditions

TERRACED HOUSE														
NET HEATED AREA								126.02 m^2						
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year	H	C	H	C	H	C	H	C	H	C	H	C	H	C
kWh/m²	185.5	5.1	154.2 83%	5.7	129.5 70%	4.8	64.2 35%	17.6	54.9 30%	15.9	50.6 27%	16.5	47.7 26%	17.1
Jan	39.1	-	33.0	-	27.9	-	16.4	-	14.2	-	13.3	-	12.7	-
Feb	29.7	-	25.0	-	21.2	-	11.6	-	10.0	-	9.3	-	8.9	-
Mar	22.1	-	18.4	-	15.5	-	7.0	-	6.0	-	5.4	-	5.1	-
Apr	9.8	-	7.7	-	6.5	-	1.0	-	0.9	-	0.7	-	0.5	-
May	3.2	0.0	2.4	0.0	2.1	-	0.1	1.2	0.1	1.2	0.1	1.3	0.0	1.4
Jun	0.6	1.5	0.5	1.6	0.5	1.3	-	4.6	-	4.1	-	4.3	-	4.4
Jul	0.0	2.3	0.0	2.6	0.0	2.2	-	6.0	-	5.3	-	5.5	-	5.6
Aug	0.2	1.3	0.2	1.6	0.2	1.3	-	4.8	-	4.3	-	4.4	-	4.6
Sep	3.4	0.0	2.4	0.0	1.9	0.0	0.0	0.9	0.0	0.9	0.0	1.0	-	1.1
Oct	14.0	-	11.4	-	9.3	-	2.9	-	2.2	-	1.8	-	1.5	-
Nov	26.0	-	21.8	-	18.1	-	9.8	-	8.2	-	7.6	-	7.2	-
Dec	37.3	-	31.5	-	26.5	-	15.4	-	13.2	-	12.4	-	11.8	-

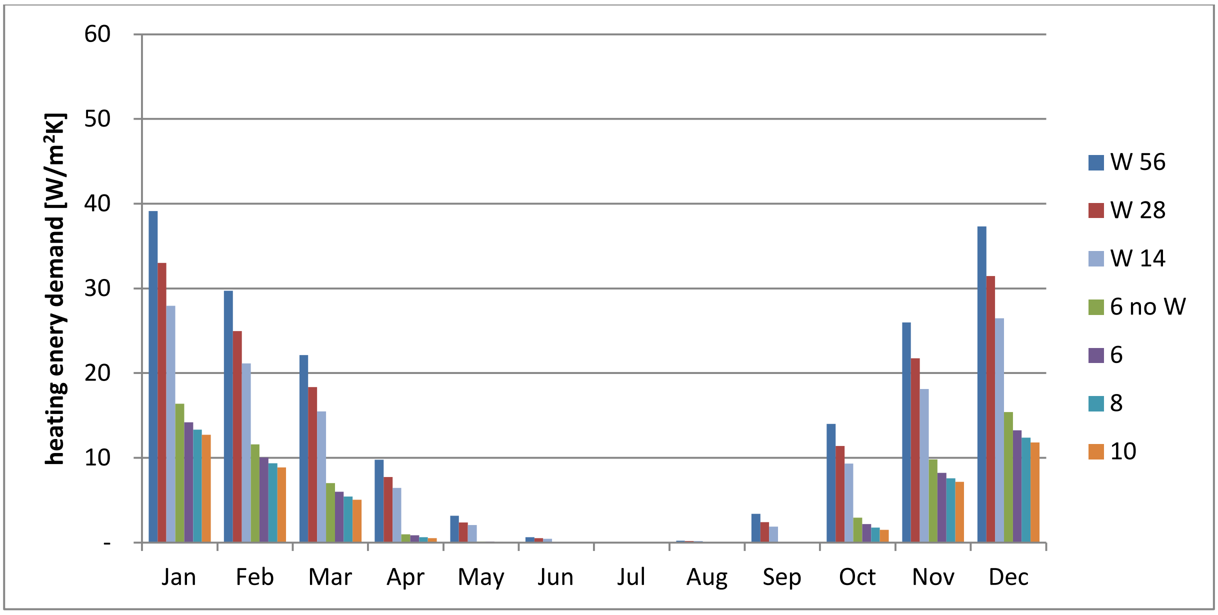


Figure 4.11 CASE 1-Energy demands before and after renovation in Budapest weather conditions

The results are shown also in the Figure 4.1, which allows a visual comparison among the cases described. Simulations assets that in Budapest climate the most effective solutions are the one concerned with the insulation of the opaque structures of the building. In fact the reduction of the due to the insulation of the envelope with a thickness of 6 cm of polystyrene allows to reduce the heating energy demand to the 35% of the before renovation value. Adding the substitution of windows with the best solution considered makes the value decrease to the 30% of the initial value.
Results show also that the thickness of the insulation have a little effect on the heating energy demand, which value shift from 30% to 27% and 26% increasing the thickness value from 6, to 8 and 10 cm.
What is noticeable is that even if the global results are not comparable with the ones achieved with the insulation of the building, the substitution of the windows allows to reduce the energy demand to the 83% and the 70% of value of base case.

*4.4.1.2 CASE **2***

The Table 4.19 and the Figure 4.12 present the results of the renovation fort the detached house in the weather conditions of Budapest. Observing the yearly values it is clear that the action 3 guarantees the higher energy saving achieved with a single action, reducing the heating energy demand to the 55% of the initial value. In fact the replacement of the windows separated from the insulation of the envelope gives much less noticeable results with a reduction of the energy demand respectively to the 90% and 86% of the initial value. On the contrary the insulation combined with much performing windows allows to reduce the energy demand from 39% to 31% respect to the action 0, actions 4 to 6.

Table 4.19. CASE 2- Energy demands before and after renovation in Budapest weather conditions

DETACHED HOUSE														
NET HEATED AREA					210.0 m^2									
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year kWh/m^2	232.2	4.1	208.4	4.5	198.6	4.2	128.5	5.4	90.5	6.5	80.0	7.2	72.7	7.7
			90%		86%		55%		39%		34%		31%	
Jan	49.8	-	45.1	-	42.9	-	29.4	-	21.5	-	19.3	-	17.8	-
Feb	37.2	-	33.6	-	32.0	-	21.6	-	15.6	-	13.9	-	12.7	-
Mar	27.2	-	24.3	-	23.1	-	15.1	-	10.4	-	9.1	-	8.3	-
Apr	11.0	-	9.4	-	9.0	-	4.8	-	2.6	-	2.0	-	1.6	-
May	2.6	0.0	1.9	0.0	1.9	0.0	0.7	0.0	0.2	0.0	0.2	0.1	0.1	0.1
Jun	0.2	1.6	0.1	1.7	0.1	1.6	-	1.6	-	1.8	-	1.9	-	2.1
Jul	-	1.8	-	2.0	-	1.9	-	2.4	-	2.9	-	3.1	-	3.2
Aug	0.0	0.6	0.0	0.7	0.0	0.7	-	1.3	-	1.7	-	2.0	-	2.2
Sep	4.0	-	3.3	-	3.1	-	0.8	0.0	0.1	0.0	0.0	0.1	0.0	0.1
Oct	18.2	-	16.4	-	15.6	-	9.0	-	5.9	-	4.9	-	4.2	-
Nov	33.6	-	30.5	-	29.0	-	19.0	-	13.6	-	12.0	-	10.9	-
Dec	48.3	-	43.9	-	41.8	-	28.2	-	20.6	-	18.5	-	17.0	-

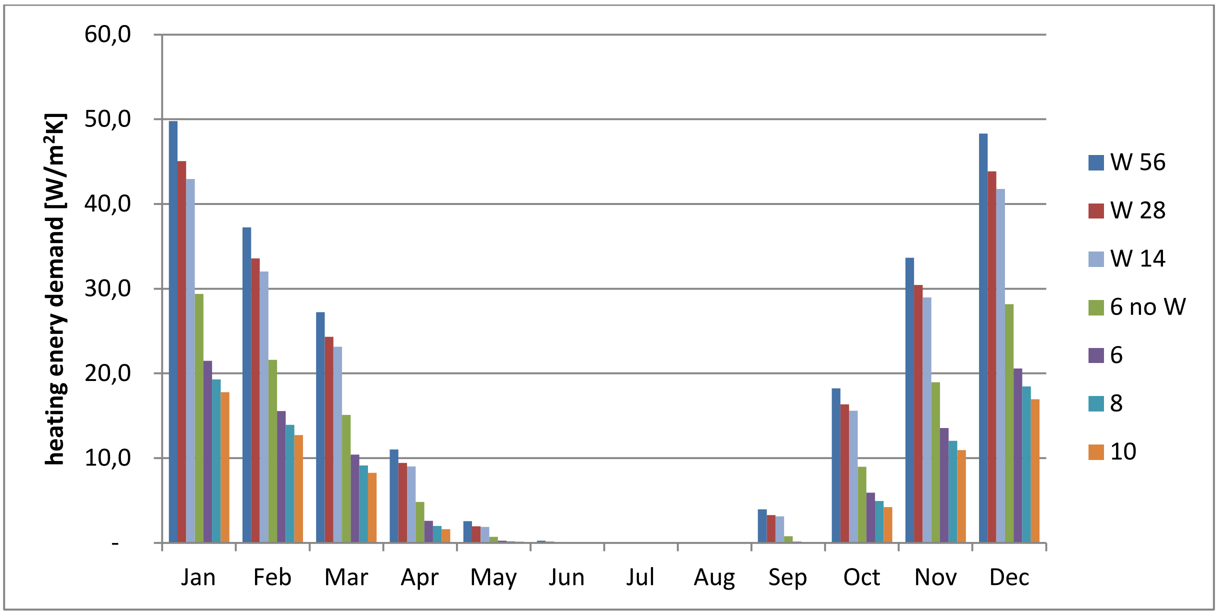


Figure 4.12. CASE 2-Energy demands before and after renovation in Budapest weather conditions

4.4.1.3 CASE 3

The Table 4.20 presents the results of the renovation fort the case 3, the apartment building with a net heated area of 1335 m^2, in the weather conditions of Budapest.

Table 4.20. CASE 3- Energy demands before and after renovation in Budapest weather conditions

APARTMENT BUILDING														
NET HEATED AREA							1335.0 m^2							
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year	H	C	H	C	H	C	H	C	H	C	H	C	H	C
kWh/m^2	132.0	4.8	80.7 61%	7.7	59.0 45%	8.5	60.8 46%	10.5	40.0 30%	12.2	37.6 28%	12.8	35.7 27%	0.2
Jan	31.7	-	21.0	-	16.2	-	16.9	0.0	12.0	0.0	11.4	0.0	11.0	-
Feb	22.5	-	14.2	0.0	10.7	0.0	11.0	0.0	7.4	0.0	7.0	0.0	6.7	-
Mar	15.1	0.0	8.5	0.0	5.8	0.0	6.0	0.0	3.3	0.0	3.0	0.0	2.7	-
Apr	4.3	0.0	1.1	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	-
May	0.7	0.1	0.2	0.3	0.0	0.4	0.0	0.6	-	1.1	-	1.2	-	-
Jun	-	1.3	-	2.0	-	2.2	-	2.7	-	3.0	-	3.1	-	0.1
Jul	-	1.9	-	2.8	-	2.9	-	3.5	-	3.7	-	3.8	-	0.1
Aug	-	1.4	-	2.2	-	2.4	-	3.0	-	3.2	-	3.3	-	0.0
Sep	0.3	0.1	-	0.3	-	0.4	-	0.6	-	1.1	-	1.2	-	-
Oct	7.9	0.0	3.5	0.0	1.7	0.0	1.6	0.0	0.4	0.0	0.3	0.0	0.2	-
Nov	19.4	0.0	12.2	0.0	8.9	0.0	9.2	0.0	5.8	0.0	5.4	0.0	5.1	-
Dec	30.1	-	20.0	-	15.3	-	15.9	0.0	11.1	0.0	10.6	0.0	10.2	-

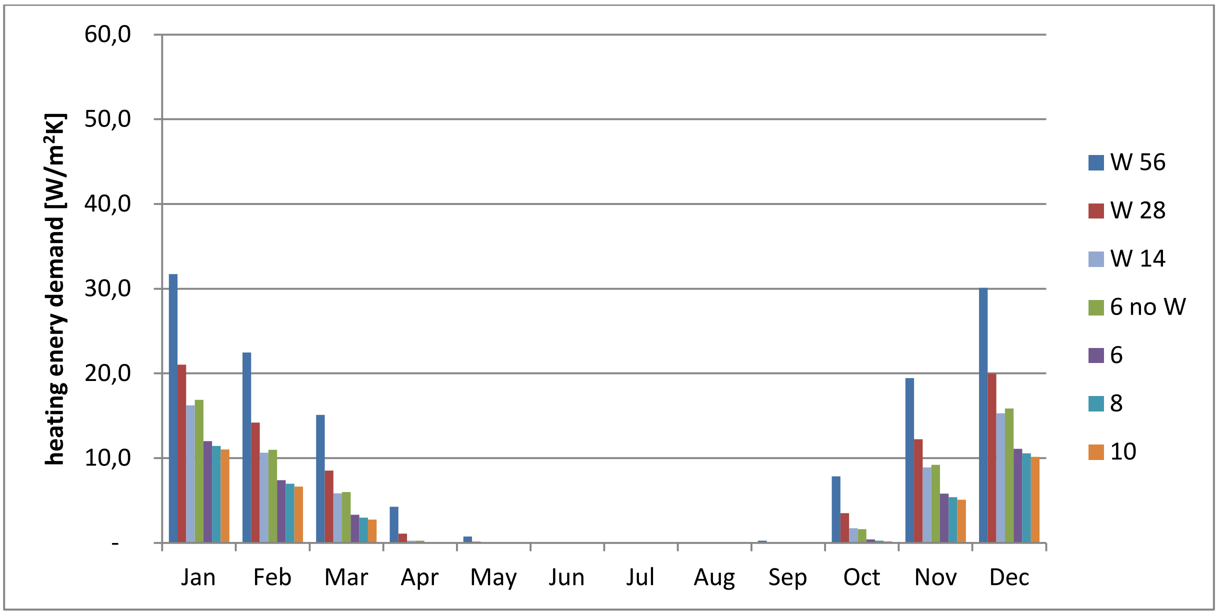


Figure 4.13. CASE 3-Energy demands before and after renovation in Budapest weather conditions

4.4.1.4 CASE 4

The Table 4.18 presents the results of the renovation fort the case 4, the apartment building with a net heated area of 680 m^2, in the weather conditions of Budapest.

Table 4.21. CASE 4- Energy demands before and after renovation in Budapest weather conditions

APARTMENT BUILDING														
NET HEATED AREA					680.0 m^2									
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year kWh/m^2	290.2	1.0	252 87%	1.0	237.6 82%	0.8	158.5 55%	0.6	120.4 42%	0.3	113.5 39%	0.4	108.6 37%	0.5
Jan	57.5	-	50.5	-	47.5	-	34.8	-	26.8	-	25.5	-	24.5	-
Feb	43.5	-	38.1	-	35.9	-	25.6	-	19.6	-	18.6	-	17.8	-
Mar	34.0	-	29.6	-	27.9	-	18.9	-	14.3	-	13.5	-	12.9	-
Apr	18.2	-	15.6	-	14.8	-	8.4	-	6.1	-	5.7	-	5.4	-
May	8.5	-	7.1	-	6.7	-	3.1	-	2.1	-	1.9	-	1.8	-
Jun	2.6	0.5	2.0	0.5	1.9	0.4	0.2	0.3	0.1	0.1	0.1	0.1	0.0	0.2
Jul	0.2	0.4	0.1	0.4	0.1	0.3	-	0.2	-	0.2	-	0.2	-	0.2
Aug	1.0	0.2	0.7	0.1	0.6	0.1	-	0.1	-	0.0	-	0.0	-	0.1
Sep	7.4	-	6.1	-	5.8	-	1.6	-	0.9	-	0.7	-	0.6	-
Oct	22.6	-	19.6	-	18.5	-	10.7	-	8.1	-	7.5	-	7.0	-
Nov	39.1	-	34.2	-	32.1	-	22.1	-	16.9	-	16.0	-	15.3	-
Dec	55.4	-	48.6	-	45.7	-	33.1	-	25.5	-	24.1	-	23.2	-

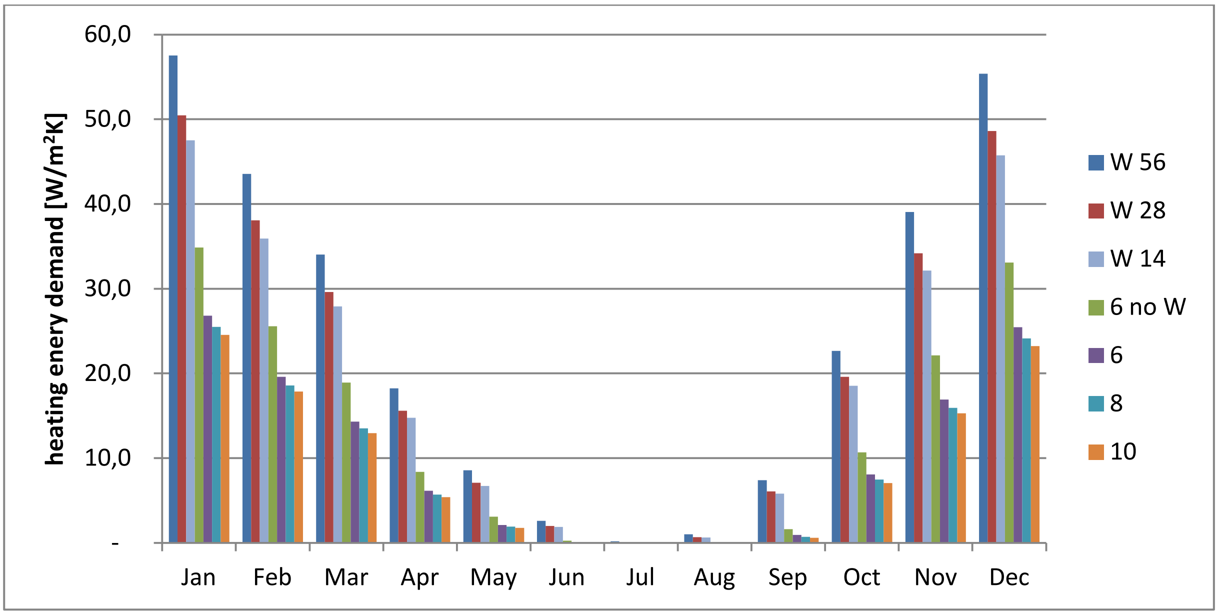


Figure 4.14. CASE 4-Energy demands before and after renovation in Budapest weather conditions

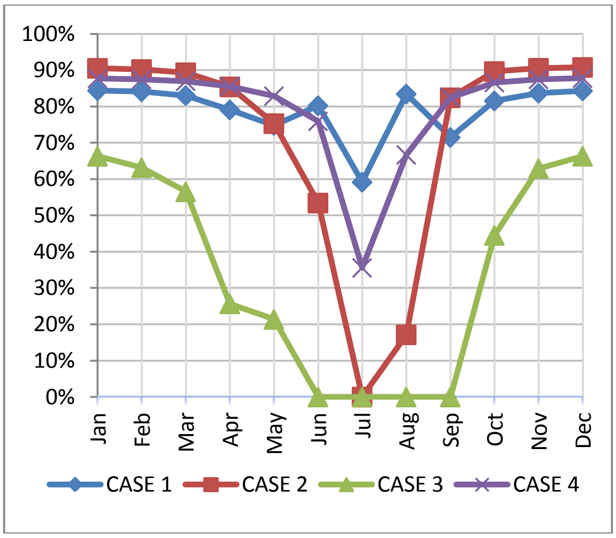
In Table 4.22 a comparison among all the actions considered is shown. The reduction of the heating energy demand is presented as a percentage of the value of the not retrofitted building (action 0), for each one of the cases studied. This kind of representation of the results aims to show in a immediate way which actions are most effective on every case study.

For example considering the action 2, the graph asset that the replacement of windows, without any other action on the insulation of the envelope, could have an high effect on the case 3, for which one this action has the same energy effect of an insulation of the building, as considered in action 3. In fact the comparison of the graphs shows a very similar trend in the energy demand.

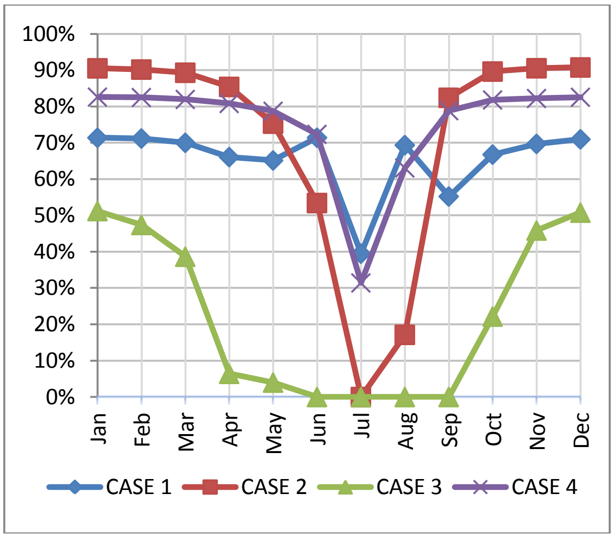
Actually the utility of an analysis like the one carried out, consists in having a quick projection of the effect of each one of the actions proposed on every one of the case studied. It could be a important instrument to evaluate in first analysis the possibilities of the building retrofit, and to make a choice on which actions are the best to achieve the expected results.

Table 4.22. Percentage of reduction of the heating energy demand for each action, Budapest

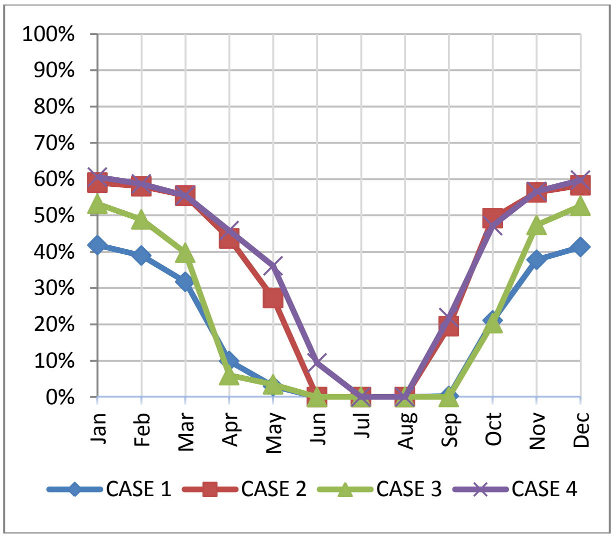
ACTION 1



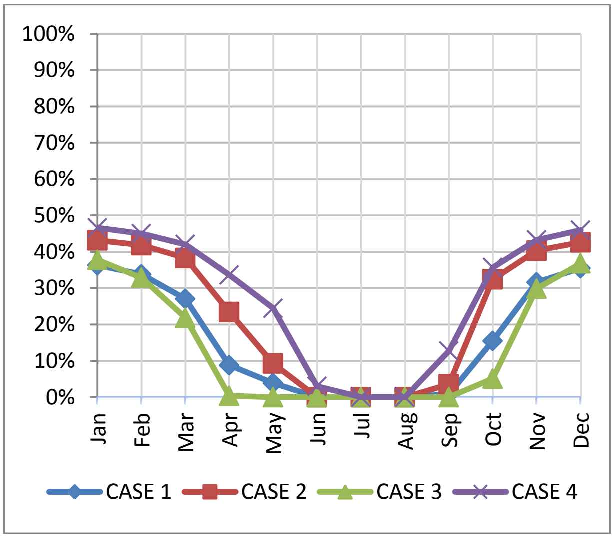
ACTION 2



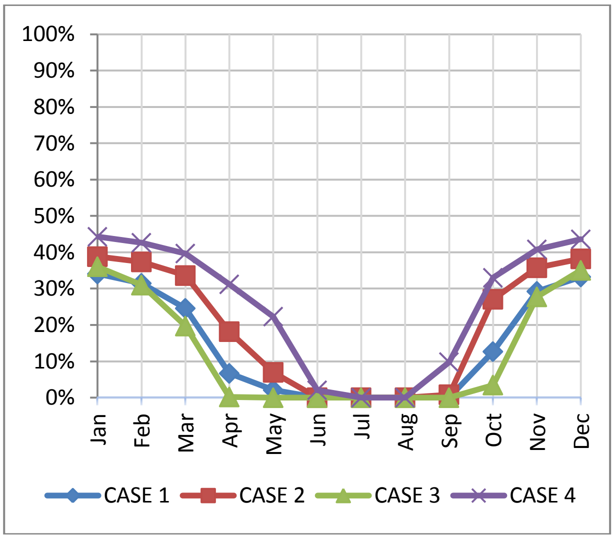
ACTION 3



ACTION 4



ACTION 5



4.4.2 VENICE – Warm climate

4.4.2.1 CASE 1

The Table 4.23 presents the results of the renovation fort the case study number 1, the terraced house, in the weather conditions of Venice. This city has been considered as example for the European warm climate.

Table 4.23. CASE 1- Energy demands before and after renovation in Venice weather conditions

TERRACED HOUSE														
NET HEATED AREA							126.02 m^2							
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year	H	C	H	C	H	C	H	C	H	C	H	C	H	C
kWh/m²	143.1	15.3	118.8	16.2	99.2	14.1	46.0	28.4	38.6	25.3	35.3	25.9	33.0	26.4
			83%		69%		32%		27%		25%		23%	
Jan	31.6	-	26.6	-	22.4	-	12.4	-	10.6	-	9.9	-	9.4	-
Feb	24.7	-	20.8	-	17.6	-	8.8	-	7.5	-	7.0	-	6.5	-
Mar	17.5	-	14.5	-	12.3	-	4.4	-	3.7	-	3.3	-	3.0	-
Apr	8.9	-	7.1	-	6.0	-	0.9	-	0.8	-	0.6	-	0.5	-
May	2.3	0.3	1.8	0.5	1.6	0.3	0.0	2.7	0.0	2.4	0.0	2.5	0.0	2.7
Jun	0.1	2.7	0.0	3.0	0.0	2.5	-	6.2	-	5.5	-	5.6	-	5.7
Jul	-	6.1	-	6.2	-	5.3	-	8.7	-	7.6	-	7.6	-	7.7
Aug	-	5.1	-	5.4	-	4.8	-	7.6	-	6.7	-	6.8	-	6.8
Sep	0.6	1.0	0.5	1.2	0.4	1.1	-	3.2	-	3.1	-	3.3	-	3.4
Oct	7.3	-	5.6	-	4.3	-	0.7	0.0	0.4	0.1	0.3	0.1	0.2	0.1
Nov	20.3	-	16.7	-	13.7	-	7.0	-	5.7	-	5.1	-	4.7	-
Dec	30.0	-	25.2	-	21.0	-	11.7	-	9.9	-	9.1	-	8.7	-

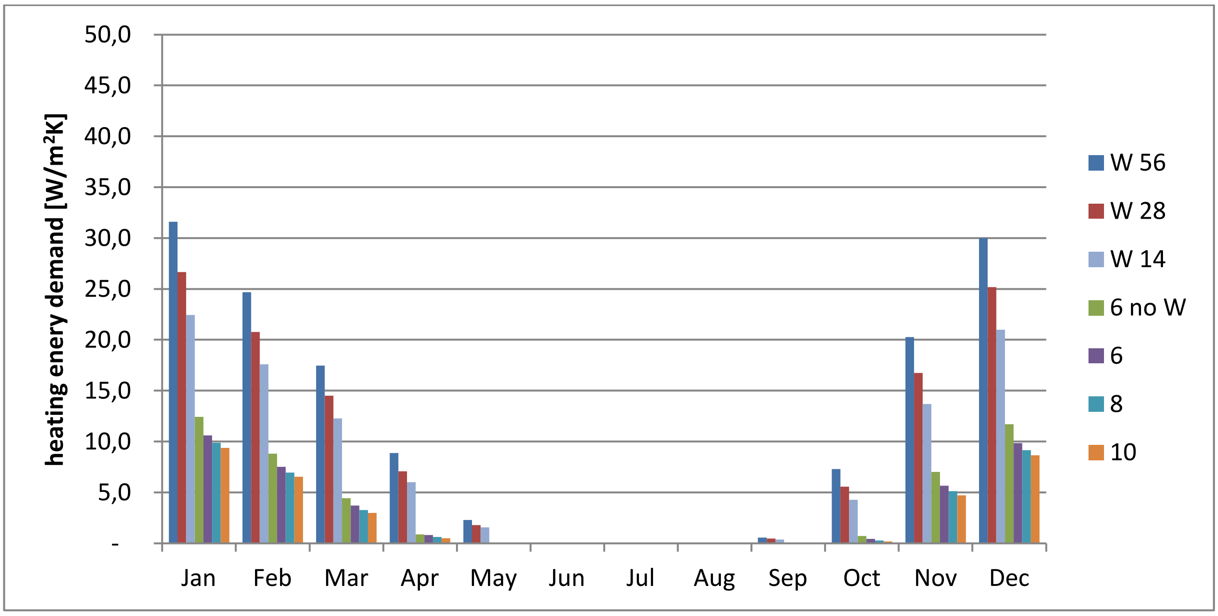


Figure 4.15 CASE 1-Energy demands before and after renovation in Venice weather conditions

4.4.2.2 CASE 2

The table 4.24 and the Figure 4.16 present the results of the renovation fort the detached house in the weather conditions of Venice.

Table 4.24. CASE 2- Energy demands before and after renovation in Venice weather conditions

DETACHED HOUSE														
NET HEATED AREA				210.0 m^2										
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year $\frac{kWh}{m^2}$	179.4	13.0	161.2	14.1	153.4	13.3	97.4	15.6	67.8	16.4	59.6	17.0	53.8	17.5
			90%		86%		54%		38%		33%		30%	
Jan	40.6	-	36.8	-	35.1	-	23.5	-	17.1	-	15.3	-	14.0	-
Feb	30.6	-	27.6	-	26.3	-	17.4	-	12.5	-	11.1	-	10.1	-
Mar	20.3	-	18.0	-	17.1	-	10.7	-	7.1	-	6.1	-	5.4	-
Apr	8.8	-	7.4	-	7.1	-	3.7	-	1.9	-	1.5	-	1.2	-
May	1.6	0.3	1.3	0.4	1.3	0.4	0.4	0.5	0.1	0.8	0.1	0.9	0.0	1.0
Jun	-	2.6	-	2.8	-	2.7	-	3.0	-	3.5	-	3.7	-	3.8
Jul	-	5.8	-	6.2	-	5.8	-	6.3	-	6.2	-	6.2	-	6.2
Aug	-	3.7	-	4.0	-	3.8	-	4.9	-	4.9	-	5.1	-	5.2
Sep	0.1	0.5	0.0	0.6	0.0	0.6	-	0.9	-	1.0	-	1.1	-	1.2
Oct	10.3	-	9.0	-	8.6	-	3.9	-	2.0	-	1.5	-	1.2	0.0
Nov	27.4	-	24.9	-	23.6	-	15.0	-	10.6	-	9.3	-	8.4	-
Dec	39.7	-	36.1	-	34.4	-	22.7	-	16.5	-	14.7	-	13.5	-

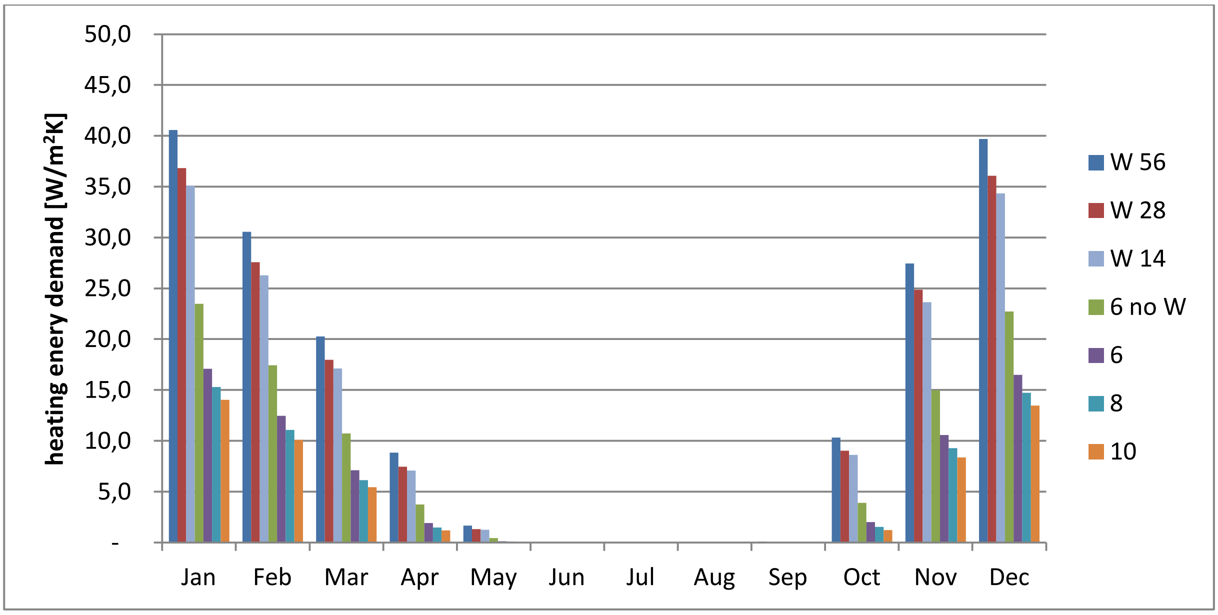


Figure 4.16. CASE 2-Energy demands before and after renovation in Venice weather conditions

4.4.2.3 CASE 3

The Table 4.25 and the Figure 4.17 present the results of the renovation fort the case 3, the apartment building with a net heated area of 1335 m^2, in the weather conditions of Venice.

Table 4.25. CASE 3- Energy demands before and after renovation in Venice weather conditions

APARTMENT BUILDING														
NET HEATED AREA	1335.0 m^2													
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh/m^2	H 99.0	C 16.3	H 61.8 62%	C 21.1	H 46.2 47%	C 21.6	H 45.5 46%	C 25.1	H 30.0 30%	C 26.4	H 27.8 28%	C 27.3	H 40.7 41%	C 1.9
Jan	24.6	-	16.6	-	12.9	-	12.8	-	9.1	-	8.6	-	9.6	-
Feb	17.8	-	11.5	-	8.7	-	8.6	-	5.8	-	5.4	-	7.2	-
Mar	10.4	-	5.6	-	3.7	-	3.6	-	2.0	-	1.8	-	4.7	-
Apr	3.5	-	1.1	-	0.6	-	0.6	-	0.2	0.0	0.1	0.0	2.2	-
May	0.4	0.5	0.0	1.3	0.0	1.6	0.0	1.9	0.0	2.6	-	2.8	0.4	-
Jun	-	2.9	-	4.3	-	4.5	-	5.1	-	5.4	-	5.6	-	0.1
Jul	-	6.2	-	7.2	-	6.9	-	7.8	-	7.5	-	7.6	-	0.7
Aug	-	5.4	-	6.4	-	6.2	-	7.1	-	6.9	-	7.1	-	0.8
Sep	-	1.2	-	2.0	-	2.3	-	3.1	-	3.6	-	3.8	-	0.2
Oct	3.0	-	1.1	0.0	0.5	0.0	0.4	0.1	0.0	0.3	0.0	0.4	1.3	-
Nov	15.2	-	9.7	-	7.1	-	6.9	-	4.1	-	3.6	-	6.0	-
Dec	24.0	-	16.3	-	12.6	-	12.5	-	8.8	-	8.2	-	9.4	-

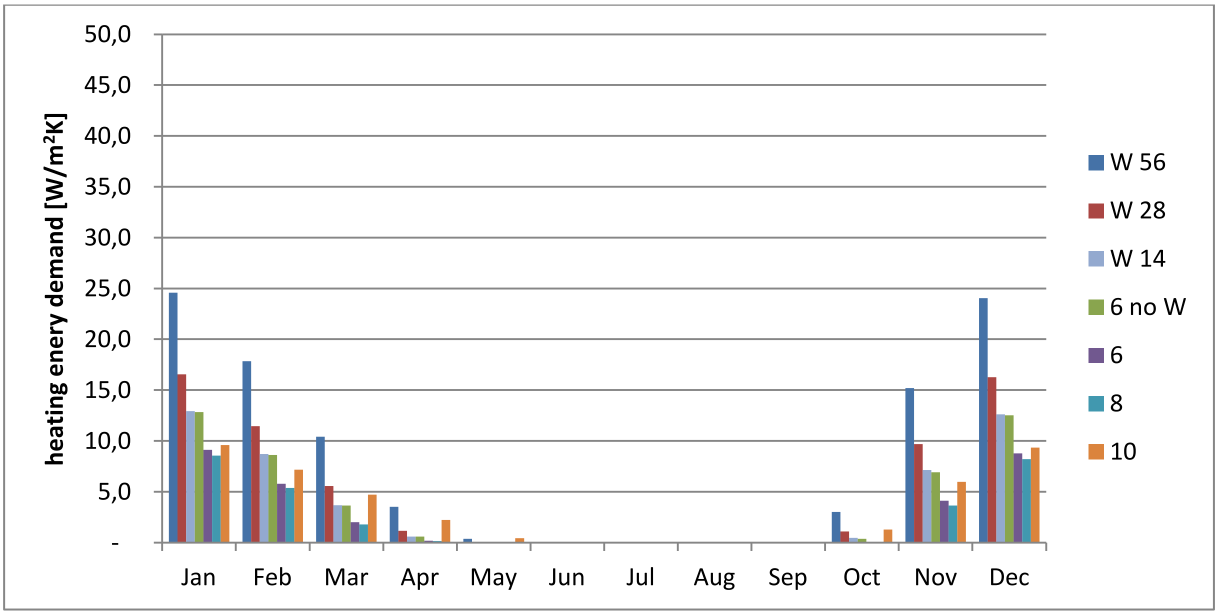


Figure 4.17. CASE 3-Energy demands before and after renovation in Venice weather conditions

4.4.2.4 CASE 4

The table 4.26 and the Figure 4.18 present the results of the renovation fort the case 4, the apartment building with a net heated area of 680 m^2, in the weather conditions of Venice.

Table 4.26. CASE 4- Energy demands before and after renovation in Venice weather conditions

APARTMENT BUILDING														
NET HEATED AREA	680.0 m^2													
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year kWh/m^2	223.5	4.2	193.8 87%	4.3	182.6 82%	3.6	117.5 53%	3.9	89.2 40%	3.2	83.7 37%	3.5	79.8 36%	3.7
Jan	46.1	-	40.4	-	38.1	-	26.8	-	20.7	-	19.6	-	18.8	-
Feb	35.8	-	31.3	-	29.5	-	20.3	-	15.5	-	14.7	-	14.1	-
Mar	26.4	-	22.9	-	21.6	-	13.7	-	10.3	-	9.7	-	9.2	-
Apr	15.9	-	13.6	-	12.8	-	7.0	-	5.0	-	4.7	-	4.4	-
May	5.4	-	4.4	-	4.2	-	1.5	-	1.0	-	0.9	-	0.8	-
Jun	0.6	0.5	0.4	0.6	0.3	0.5	-	0.3	-	0.2	-	0.2	-	0.3
Jul	-	1.7	-	1.8	-	1.6	-	1.5	-	1.3	-	1.4	-	1.5
Aug	-	1.6	-	1.7	-	1.4	-	1.7	-	1.3	-	1.5	-	1.5
Sep	1.7	0.3	1.1	0.3	1.0	0.2	-	0.4	-	0.3	-	0.4	-	0.4
Oct	14.1	-	12.0	-	11.4	-	4.7	-	3.3	-	2.8	-	2.5	-
Nov	31.9	-	27.9	-	26.2	-	17.2	-	13.1	-	12.3	-	11.7	-
Dec	45.5	-	39.9	-	37.5	-	26.3	-	20.2	-	19.1	-	18.3	-

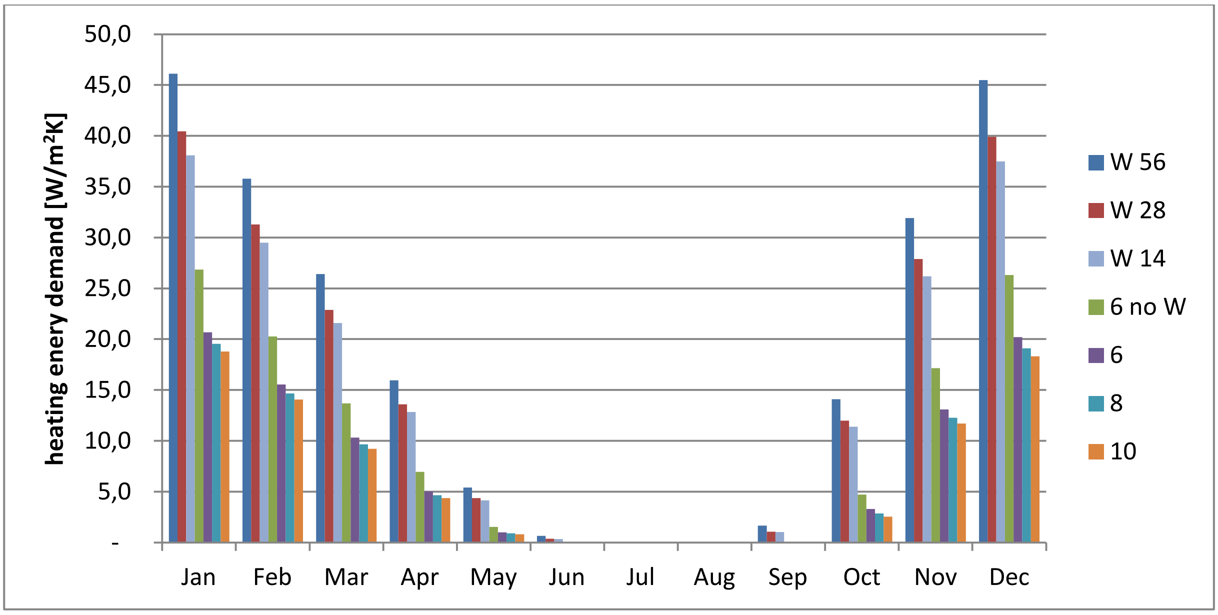
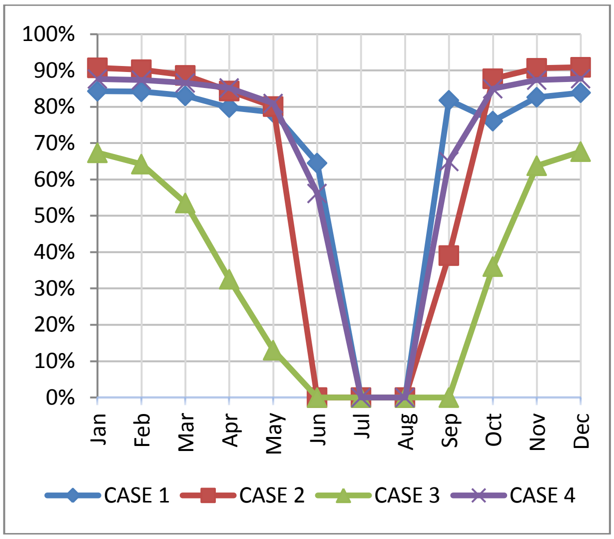


Figure 4.18. CASE 4-Energy demands before and after renovation in Venice weather conditions

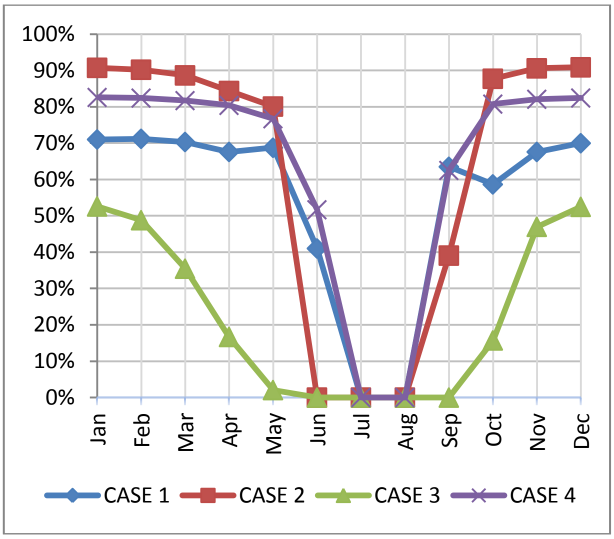
In Table 4.27 a comparison among all the actions considered is shown. The reduction of the heating energy demand is presented as a percentage of the value of the not retrofitted building (action 0), for each one of the cases studied.

Table 4.27. Percentage of reduction of the heating energy demand for each action, Venice

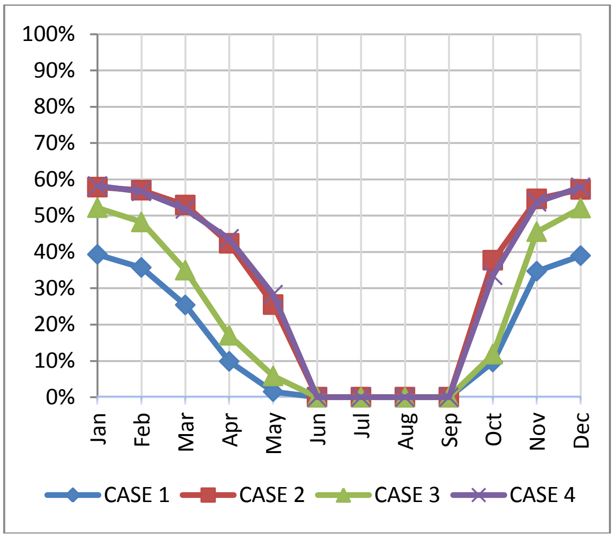
ACTION 1



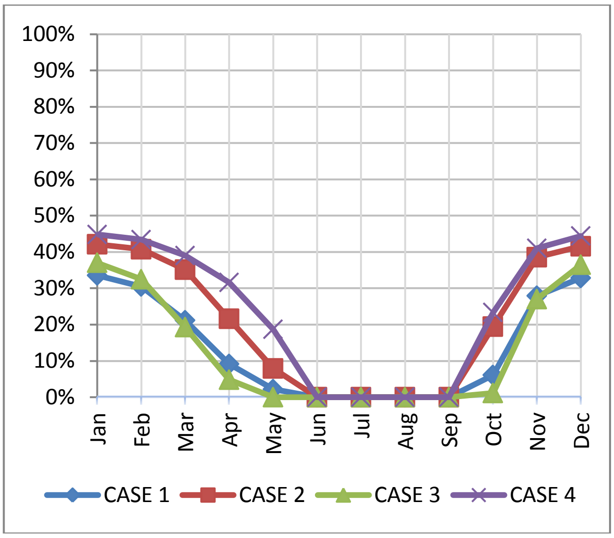
ACTION 2



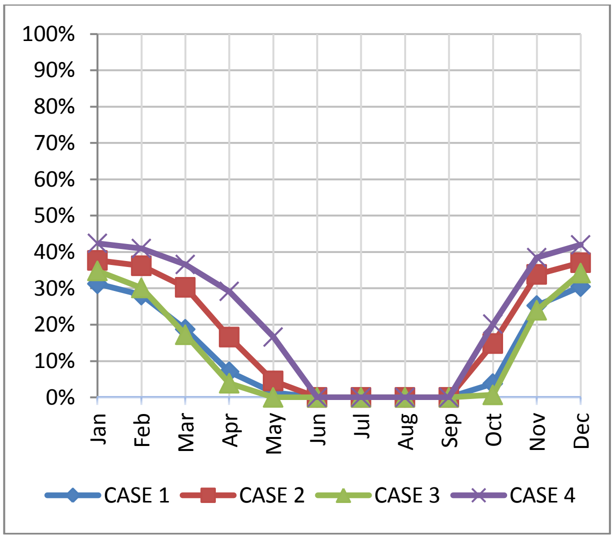
ACTION 3



ACTION 4



ACTION 5



4.4.3 ATHENS – Mediterranean climate

4.4.3.1 CASE 1

The Table 4.28 and the Figure 4.19 present the results of the renovation fort the case study number 1, the terraced house, in the weather conditions of Athens. This city has been considered as example for the European Mediterranean climate.

Table 4.28. CASE 1- Energy demands before and after renovation in Athens weather conditions

TERRACED HOUSE														
NET HEATED AREA							126.02 m^2							
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh/m^2	H 78.7	C 39.3	H 64.6 82%	C 38.6	H 53.5 68%	C 33.8	H 18.0 23%	C 47.1	H 14.4 18%	C 41.7	H 12.6 16%	C 42.2	H 11.3 14%	C 42.5
Jan	19.2	-	16.0	-	13.4	-	5.8	-	4.7	-	4.2	-	3.9	-
Feb	15.4	-	12.8	-	10.8	-	4.0	-	3.2	-	2.9	-	2.6	-
Mar	12.2	-	10.0	-	8.4	-	2.4	-	1.9	-	1.7	-	1.5	-
Apr	3.8	0.0	2.8	0.0	2.3	-	0.1	0.7	0.1	0.7	0.1	0.8	0.0	0.9
May	0.6	1.6	0.5	1.7	0.4	1.4	-	4.5	0.0	4.0	-	4.2	-	4.3
Jun	-	7.8	-	7.7	-	6.7	-	9.2	-	8.1	-	8.1	-	8.1
Jul	-	12.5	-	11.8	-	10.2	-	12.0	-	10.4	-	10.4	-	10.3
Aug	-	11.9	-	11.4	-	9.9	-	11.6	-	10.1	-	10.1	-	10.0
Sep	0.0	5.4	0.0	5.6	0.0	5.2	-	7.2	-	6.4	-	6.5	-	6.6
Oct	2.0	0.2	1.5	0.3	1.0	0.4	-	1.9	0.0	2.0	-	2.1	-	2.2
Nov	8.8	-	7.0	-	5.5	-	1.0	-	0.6	-	0.4	-	0.3	-
Dec	16.8	-	14.0	-	11.6	-	4.8	-	3.8	-	3.3	-	3.0	-

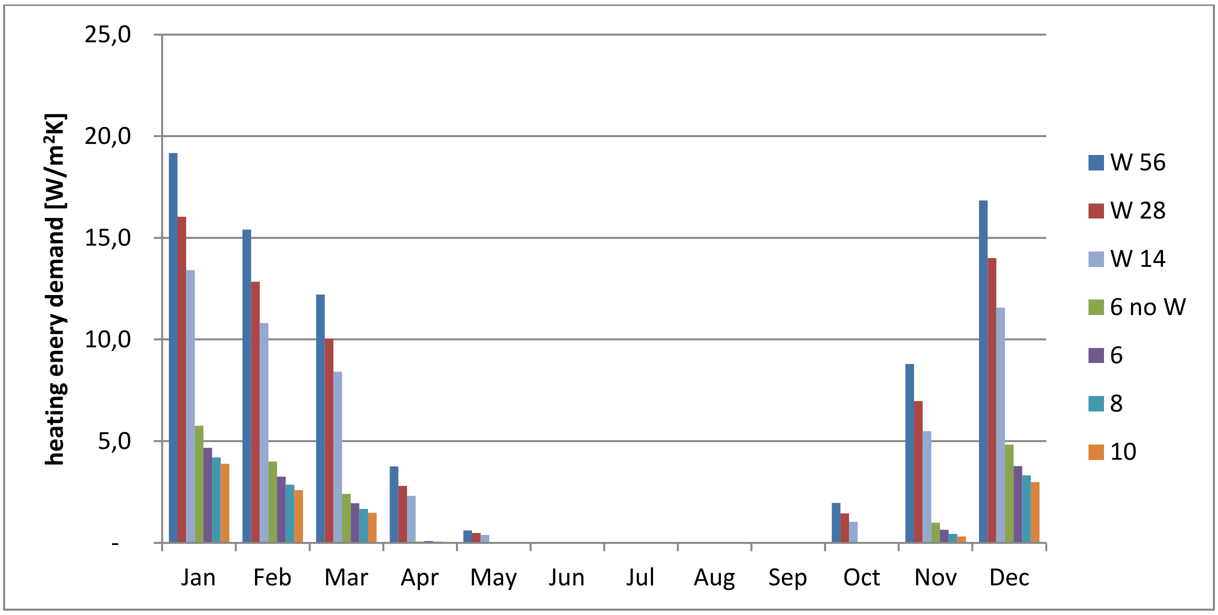


Figure 4.19. CASE 1-Energy demands before and after renovation in Athens weather conditions

4.4.3.2 CASE 2

The Table 4.29 and the Figure 4.20 present the results of the renovation fort the detached house in the weather conditions of Athens.

Table 4.29. CASE 2- Energy demands before and after renovation in Athens weather conditions

DETACHED HOUSE														
NET HEATED AREA	210.0 m^2													
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh/m²	H	C	H	C	H	C	H	C	H	C	H	C	H	C
	100	35.1	90.2 90%	35.1	86.1 86%	32.9	49.6 49%	35.3	33.7 34%	32.2	28.8 29%	32.5	25.4 25%	32.7
Jan	24.8	-	22.4	-	21.4	-	13.3	-	9.5	-	8.3	-	7.5	-
Feb	19.3	-	17.3	-	16.5	-	10.1	0.0	7.0	-	6.1	-	5.5	-
Mar	14.5	-	12.8	-	12.3	-	7.2	0.0	4.7	-	4.0	-	3.5	-
Apr	3.9	-	3.2	-	3.1	-	0.9	0.0	0.3	-	0.2	-	0.1	-
May	0.3	1.3	0.3	1.5	0.3	1.4	0.1	1.6	0.0	1.7	-	1.9	-	2.1
Jun	-	6.9	-	7.1	-	6.7	-	7.3	-	6.8	-	6.8	-	6.9
Jul	-	12.4	-	12.2	-	11.4	-	11.1	-	9.7	-	9.5	-	9.4
Aug	-	11.1	-	10.9	-	10.2	-	10.4	-	9.2	-	9.1	-	9.0
Sep	-	3.3	-	3.4	-	3.2	-	4.7	-	4.6	-	4.8	-	5.0
Oct	2.5	-	2.1	-	2.0	-	0.6	0.1	0.1	0.1	0.0	0.2	-	0.4
Nov	12.3	-	11.0	-	10.6	-	5.4	0.0	3.4	-	2.7	-	2.1	-
Dec	23.0	-	20.9	-	20.0	-	12.0	0.0	8.6	-	7.4	-	6.7	-

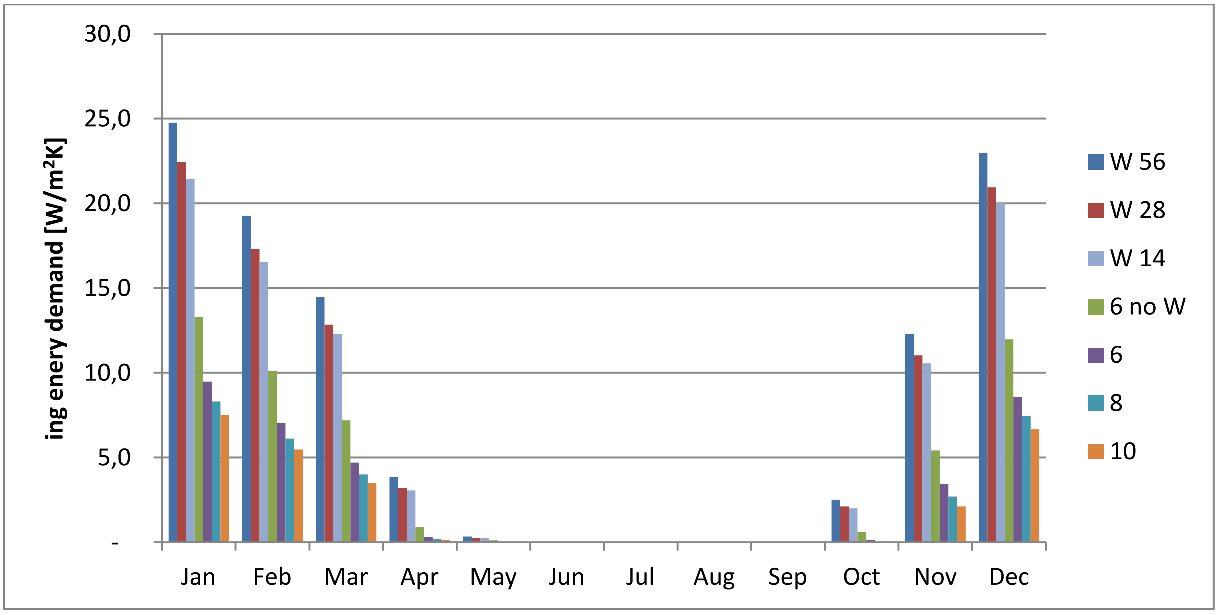


Figure 4.20. CASE 2-Energy demands before and after renovation in Athens weather conditions

4.4.3.3 CASE 3

The Table 4.30 and the Figure 4.21 present the results of the renovation fort the case 3, the apartment building with a net heated area of 1335 m^2, in the weather conditions of Athens.

Table 4.30. CASE 3- Energy demands before and after renovation in Athens weather conditions

APARTMENT BUILDING														
NET HEATED AREA							1335.0 m^2							
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year $\frac{kWh}{m^2}$	43.6	36.5	23.1	38.8	15.2	36.8	13.9	43.2	6.7	41.9	5.6	42.8	4.9	7.4
			53%		35%		32%		15%		13%		11%	
Jan	12.0	-	7.1	-	5.0	-	4.7	-	2.6	-	2.3	-	2.1	-
Feb	9.0	-	4.9	-	3.2	-	3.0	-	1.4	-	1.1	-	1.0	-
Mar	6.6	-	3.2	-	2.0	-	2.0	-	0.9	-	0.7	-	0.6	-
Apr	0.7	0.0	0.1	0.1	0.0	0.2	0.0	0.4	0.0	0.9	0.0	1.1	-	-
May	0.1	1.8	0.0	2.6	-	2.9	-	3.6	-	4.2	-	4.4	-	0.1
Jun	-	7.1	-	7.7	-	7.2	-	8.2	-	7.7	-	7.8	-	1.1
Jul	-	11.1	-	10.7	-	9.6	-	10.9	-	9.8	-	9.8	-	2.5
Aug	-	10.7	-	10.4	-	9.4	-	10.7	-	9.7	-	9.7	-	2.5
Sep	-	5.5	-	6.3	-	6.0	-	7.1	-	6.9	-	7.0	-	1.2
Oct	0.4	0.4	0.0	1.1	-	1.5	-	2.2	-	2.8	-	2.9	-	0.0
Nov	4.1	-	1.5	-	0.5	-	0.3	-	0.0	-	0.0	-	0.0	-
Dec	10.7	-	6.4	-	4.4	-	3.9	-	1.8	-	1.5	-	1.2	-

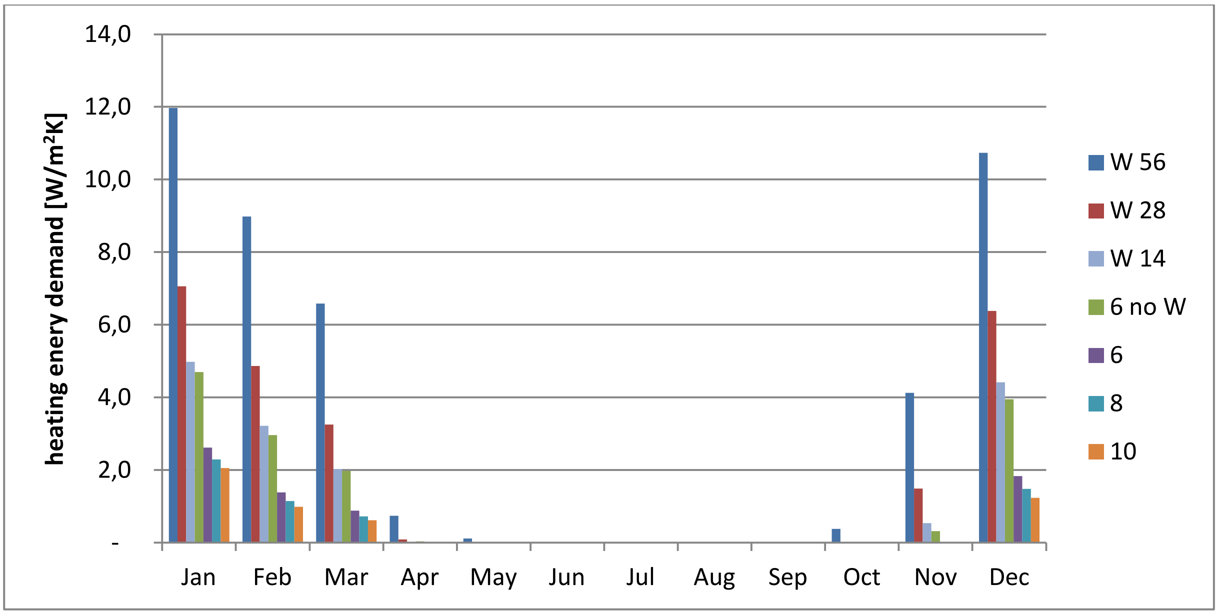


Figure 4.21. CASE 3-Energy demands before and after renovation in Athens weather conditions

4.4.3.4 CASE 4

The Table 4.31 and Figure 4.22 present the results of the renovation fort the case 4, the apartment building with a net heated area of 680 m^2, in the weather conditions of Athens.

Table 4.31. CASE 4- Energy demands before and after renovation in Athens weather conditions

APARTMENT BUILDING														
NET HEATED AREA							680.0 m^2							
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh/m^2	H	C	H	C	H	C	H	C	H	C	H	C	H	C
	129	20.5	112	20	106	17.5	58.7	17	44.8	14	41.4	14	39.0	14.5
			86%	96%	82%	86%	45%	85%	35%	67%	32%	69%	30%	71%
Jan	28.2	-	24.6	-	23.3	-	14.4	-	11.2	-	10.4	-	9.9	-
Feb	23.3	-	20.3	-	19.2	-	11.7	-	9.0	-	8.4	-	8.0	-
Mar	20.1	-	17.5	-	16.5	-	9.7	-	7.4	-	6.9	-	6.6	-
Apr	9.5	-	8.0	-	7.6	-	3.0	-	2.1	-	1.8	-	1.7	-
May	2.3	0.3	1.8	0.3	1.7	0.2	0.3	0.2	0.2	0.1	0.2	0.1	0.2	0.1
Jun	-	3.0	-	2.9	-	2.6	-	2.5	-	2.0	-	2.1	-	2.2
Jul	-	7.6	-	7.3	-	6.6	-	6.0	-	4.8	-	4.9	-	4.9
Aug	-	7.3	-	6.9	-	6.2	-	6.1	-	4.8	-	4.9	-	4.9
Sep	0.0	2.3	0.0	2.2	-	1.9	-	2.6	-	2.1	-	2.2	-	2.4
Oct	4.5	-	3.6	-	3.4	-	0.7	0.0	0.4	-	0.2	0.0	0.2	0.0
Nov	15.3	-	13.2	-	12.5	-	5.9	-	4.5	-	4.0	-	3.7	-
Dec	26.1	-	22.9	-	21.6	-	12.9	-	10.0	-	9.3	-	8.8	-

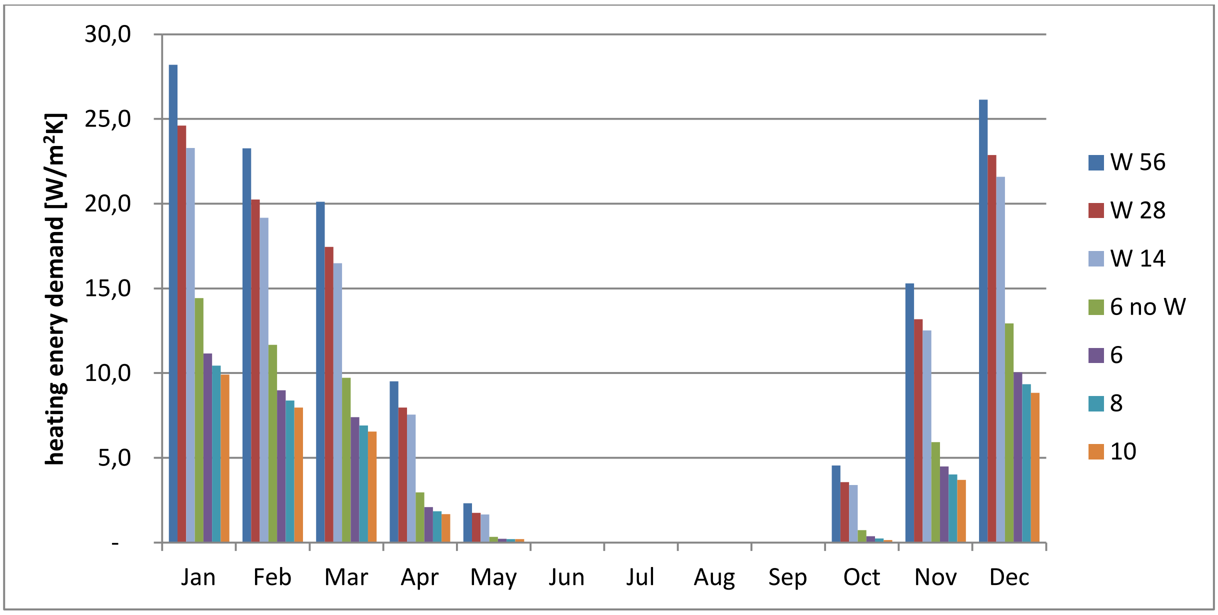
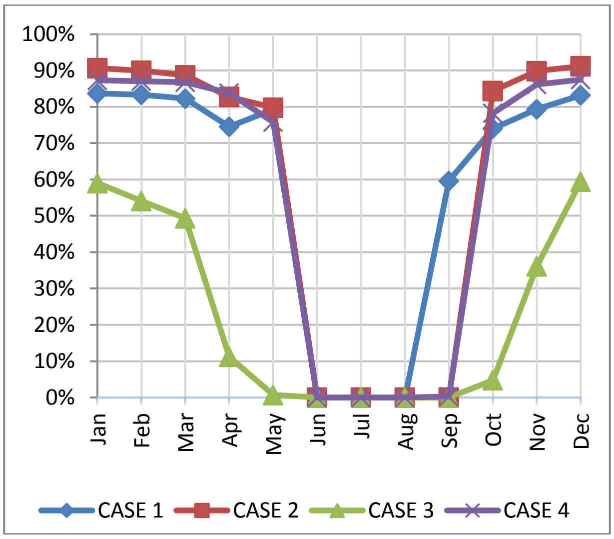


Figure 4.22. CASE 4-Energy demands before and after renovation in Athens weather conditions

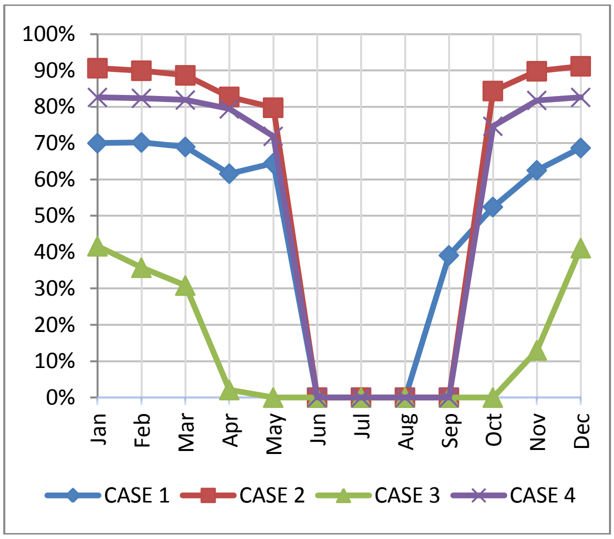
In Table 4.32 a comparison among all the actions considered is shown. The reduction of the heating energy demand is presented as a percentage of the value of the not retrofitted building (action 0), for each one of the cases studied.

Table 4.32. Percentage of reduction of the heating energy demand for each action, Athens

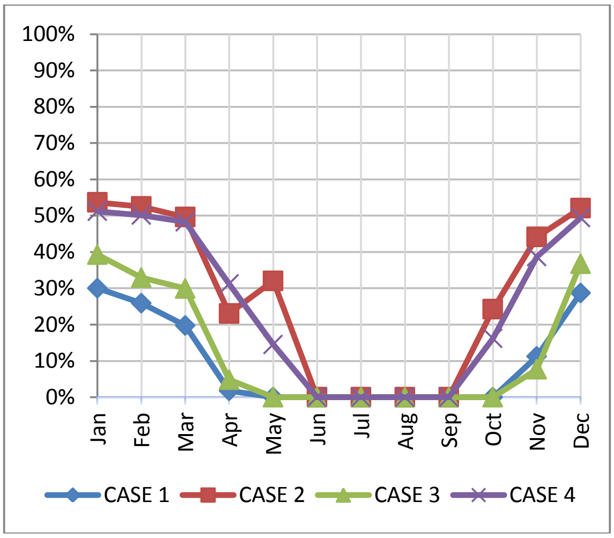
ACTION 1



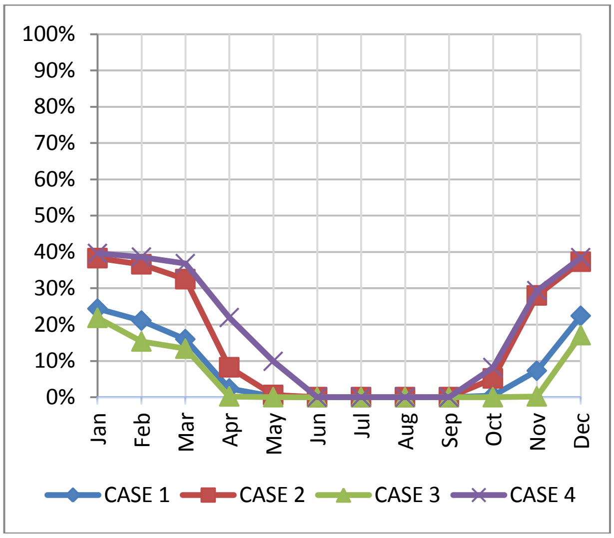
ACTION 2



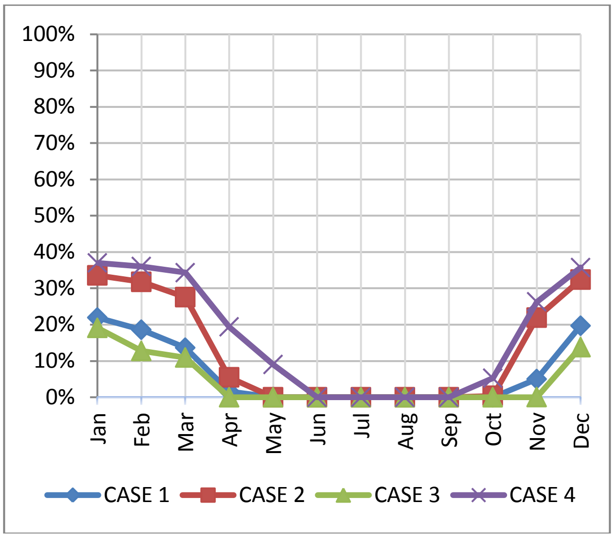
ACTION 3



ACTION 4



ACTION 5



4.4.3.5 HELSINKI – Cold climate

4.4.3.6 CASE 1

The Table 4.33 presents the results of the renovation fort the case study number 1, the terraced house, in the weather conditions of Helsinki. This city has been considered as example for the European Cold Northern climate. To allow a comparison of the effect of the building renovation on the only basis of the external climate and of the chosen action for each case study, heating and cooling season have not been considered as regulated by national laws.

Table 4.33. CASE 1- Energy demands before and after renovation in Helsinki weather conditions

TERRACED HOUSE														
	NET HEATED AREA							126.02 m^2						
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh m^2	H 287	C 0.3	H 241 84%	C 0.6	H 205 71%	C 0.4	H 108 38%	C 8.5	H 93.8 33%	C 7.8	H 87.4 30%	C 8.4	H 82.9 29%	C 8.9
Jan	47.6	-	40.5	-	34.5	-	20.9	-	18.2	-	17.2	-	16.5	-
Feb	42.6	-	36.2	-	30.9	-	18.0	-	15.9	-	14.9	-	14.3	-
Mar	36.0	-	30.3	-	26.0	-	13.6	-	12.0	-	11.2	-	10.6	-
Apr	23.2	-	19.2	-	16.5	-	6.4	-	5.7	-	5.1	-	4.7	-
May	9.8	-	7.8	-	6.8	-	1.3	0.5	1.3	0.4	1.0	0.5	0.9	0.6
Jun	2.9	0.1	2.1	0.2	1.8	0.1	0.0	2.9	0.0	2.6	0.0	2.7	-	2.9
Jul	0.9	0.2	0.8	0.4	0.7	0.3	-	3.8	-	3.4	-	3.7	-	3.8
Aug	3.0	0.0	2.2	0.0	1.8	0.0	-	1.3	0.0	1.3	-	1.5	-	1.6
Sep	13.9	-	11.2	-	9.1	-	3.0	-	2.3	0.0	1.9	0.0	1.7	0.0
Oct	25.9	-	21.6	-	17.9	-	9.7	-	8.1	-	7.5	-	7.0	-
Nov	35.4	-	29.9	-	25.0	-	15.1	-	12.9	-	12.1	-	11.5	-
Dec	46.2	-	39.2	-	33.2	-	20.1	-	17.5	-	16.4	-	15.7	-

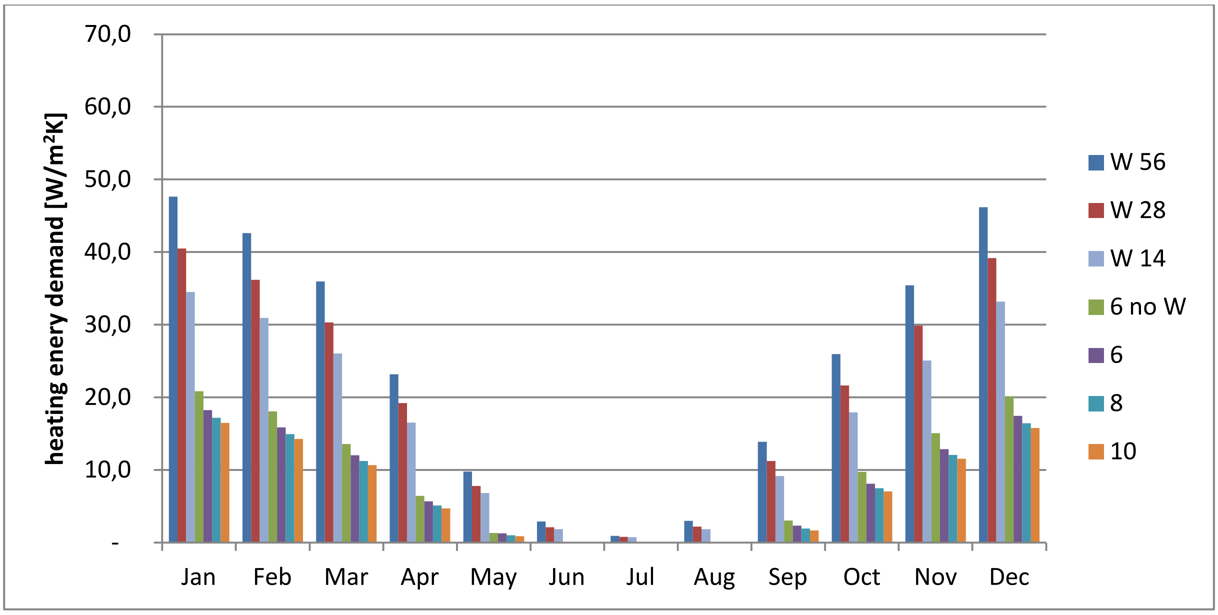


Figure 4.23 CASE 1-Energy demands before and after renovation in Helsinki weather conditions

The analysis have been carried out accounting the energy demands needed by the case studies to maintain a minimum temperature of 20°C and a maximum temperature of 26°C in every climate. The line that presents the overall energy demand during the year, shows also the percentage value of the heating energy demand of each solution compared to the situation before renovation. The results are shown also in the Figure 4.23 which allows a visual comparison among the cases described.

4.4.3.7 CASE 2

The Table 4.34 and the Figure 4.24 present the results of the renovation fort the detached house in the weather conditions of Helsinki.

Table 4.34. CASE 2- Energy demands before and after renovation in Helsinki weather conditions

DETACHED HOUSE														
NET HEATED AREA			210.0 m^2											
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh m^2	H 357	C 0.3	H 321 90%	C 0.6	H 306 86%	C 0.5	H 204 57%	C 0.6	H 147 41%	C 1.4	H 132 37%	C 1.8	H 121 34%	C 2.2
Jan	61.0	-	55.4	-	52.9	-	36.7	-	27.3	-	24.7	-	22.9	-
Feb	53.1	-	48.1	-	45.9	-	31.9	-	23.6	-	21.3	-	19.7	-
Mar	43.7	-	39.2	-	37.5	-	25.6	-	18.5	-	16.6	-	15.3	-
Apr	27.1	-	24.0	-	22.9	-	15.0	-	10.2	-	8.9	-	8.0	-
May	9.5	-	7.9	-	7.6	-	4.3	-	2.4	-	2.0	-	1.7	-
Jun	2.0	0.2	1.4	0.3	1.3	0.3	0.1	0.2	-	0.6	-	0.7	-	0.8
Jul	0.1	0.2	0.0	0.3	0.0	0.3	-	0.3	-	0.8	-	1.1	-	1.3
Aug	2.7	-	2.0	0.0	1.9	-	0.2	0.0	0.0	0.1	-	0.1	-	0.1
Sep	17.4	-	15.4	-	14.6	-	8.5	-	5.3	-	4.3	-	3.7	-
Oct	33.9	-	30.7	-	29.2	-	18.9	-	13.4	-	11.8	-	10.7	-
Nov	46.5	-	42.3	-	40.2	-	27.2	-	19.9	-	17.9	-	16.5	-
Dec	59.9	-	54.5	-	52.0	-	35.7	-	26.5	-	23.9	-	22.1	-

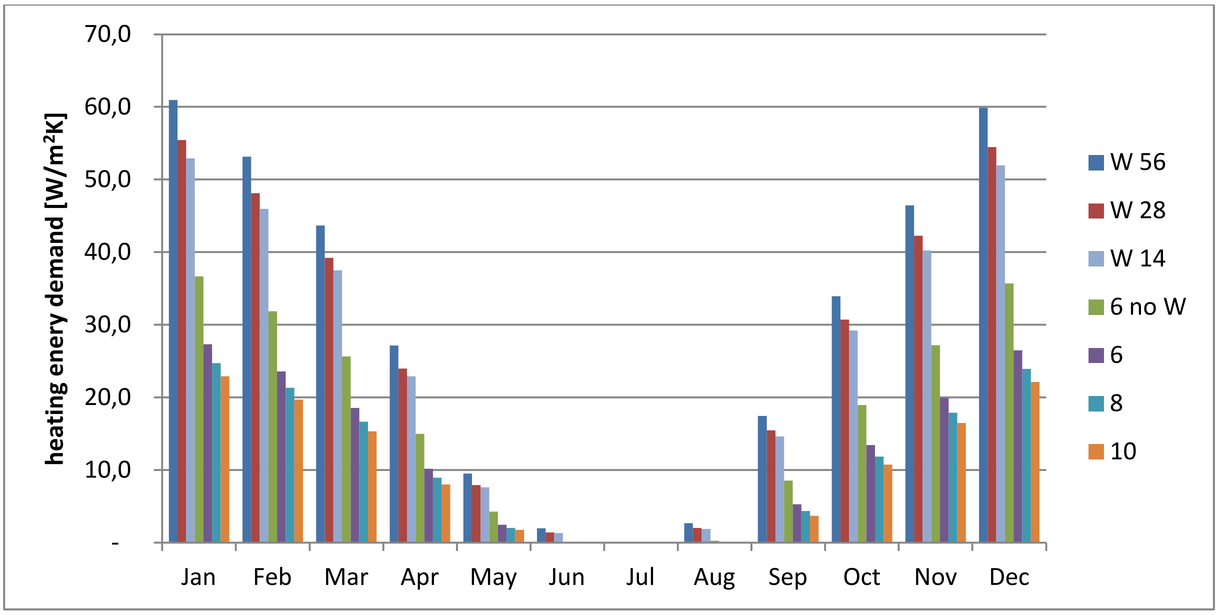


Figure 4.24. CASE 2-Energy demands before and after renovation in Helsinki weather conditions

4.4.3.8 CASE 3

The Table 4.35 and Figure 4.25 present the results of the renovation fort the case 3, the apartment building with a net heated area of 1335 m^2, in the weather conditions of Helsinki.

Table 4.35. CASE 3- Energy demands before and after renovation in Helsinki weather conditions

APARTMENT BUILDING														
NET HEATED AREA							1335.0 m^2							
	ACTION 0		ACTION 1		ACTION 2		ACTION 3		ACTION 4		ACTION 5		ACTION 6	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
Year kWh/m^2	H	C	H	C	H	C	H	C	H	C	H	C	H	C
	139	0.5	95.9 69%	1.9	77.0 55%	2.7	75.3 54%	3.4	56.0 40%	5.0	52.9 38%	5.4	50.6 36%	-
Jan	25.5	-	18.5	-	15.3	-	15.0	-	11.7	-	11.2	-	10.8	-
Feb	21.7	-	15.4	-	12.7	-	12.4	-	9.6	-	9.1	-	8.8	-
Mar	17.1	-	11.5	-	9.3	-	9.0	-	6.7	-	6.4	-	6.1	-
Apr	10.0	-	5.9	-	4.4	-	4.3	-	2.8	-	2.6	-	2.4	-
May	2.8	-	1.2	0.0	0.8	0.0	0.8	0.1	0.4	0.3	0.4	0.4	0.3	-
Jun	0.1	0.2	-	0.7	-	1.0	-	1.1	-	1.6	-	1.7	-	-
Jul	-	0.3	-	1.1	-	1.4	-	1.7	-	2.2	-	2.3	-	-
Aug	0.1	0.0	-	0.1	-	0.3	-	0.5	-	0.9	-	1.0	-	-
Sep	5.6	-	3.0	-	2.0	-	1.8	-	0.9	0.0	0.7	0.0	0.6	-
Oct	12.8	-	8.7	-	6.7	-	6.5	-	4.5	-	4.2	-	4.0	-
Nov	18.9	-	13.6	-	11.0	-	10.8	-	8.1	-	7.7	-	7.4	-
Dec	24.9	-	18.1	-	14.8	-	14.6	-	11.2	-	10.7	-	10.3	-

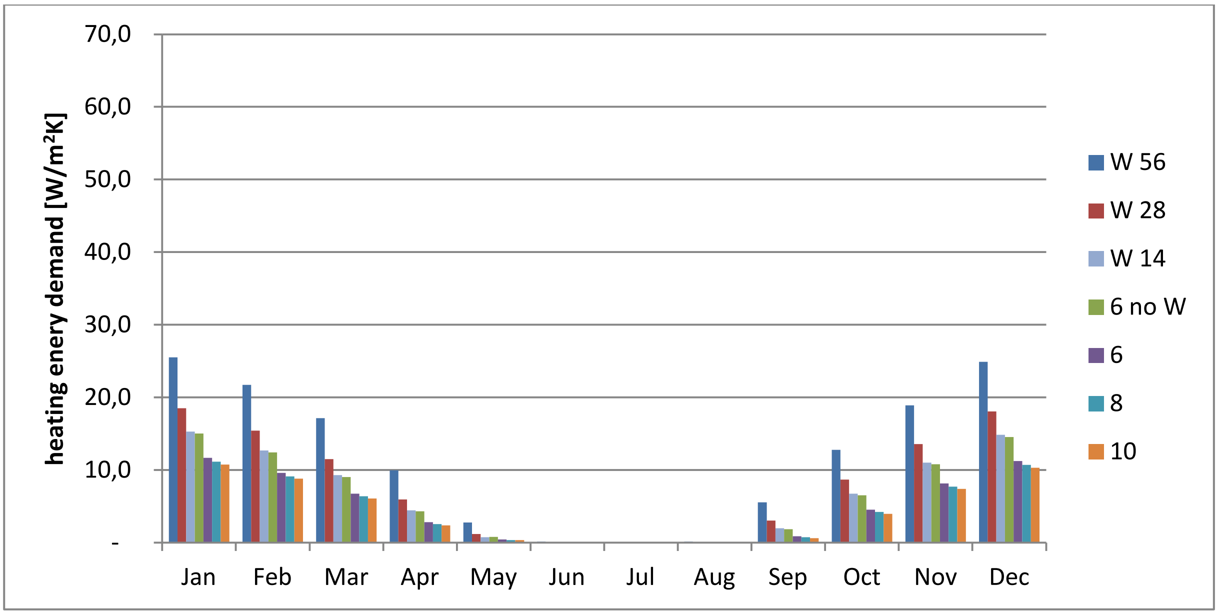


Figure 4.25. CASE 3-Energy demands before and after renovation in Helsinki weather conditions

4.4.3.9 CASE 4

The Table 4.36 and the Figure 4.26 present the results of the renovation fort the case 4, the apartment building with a net heated area of 680 m^2, in the weather conditions of Helsinki.

Table 4.36. CASE 4- Energy demands before and after renovation in Helsinki weather conditions

APARTMENT BUILDING														
NET HEATED AREA							680.0 m^2							
	ACTION 0		**ACTION 1**		**ACTION 2**		**ACTION 3**		**ACTION 4**		**ACTION 5**		**ACTION 6**	
	ANTE W 56		ANTE W 28		ANTE W 14		RETROFIT 6 no W		RETROFIT 6		RETROFIT 8		RETROFIT 10	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Year kWh/m^2	386	-	335 87%	-	314 82%	-	225 58%	-	169 44%	-	160 42%	-	154 40%	-
Jan	61.0	-	53.6	-	50.3	-	38.6	-	29.5	-	28.2	-	27.3	-
Feb	52.9	-	46.3	-	43.6	-	33.0	-	25.2	-	24.1	-	23.3	-
Mar	44.9	-	39.0	-	36.8	-	27.1	-	20.5	-	19.5	-	18.9	-
Apr	31.5	-	27.1	-	25.6	-	18.0	-	13.4	-	12.7	-	12.2	-
May	16.3	-	13.7	-	12.9	-	7.7	-	5.4	-	5.1	-	4.8	-
Jun	7.2	-	5.8	-	5.4	0.0	2.2	-	1.2	-	1.1	-	1.0	-
Jul	2.7	-	2.0	-	1.9	0.0	0.2	-	0.1	-	0.1	-	0.1	-
Aug	7.2	-	5.7	-	5.4	0.0	1.4	-	0.6	-	0.5	-	0.4	-
Sep	20.5	-	17.6	-	16.5	-	10.2	-	7.4	-	6.9	-	6.5	-
Oct	34.8	-	30.3	-	28.4	-	19.9	-	14.9	-	14.1	-	13.5	-
Nov	46.9	-	41.1	-	38.4	-	28.7	-	21.8	-	20.7	-	20.0	-
Dec	60.0	-	52.6	-	49.3	-	37.6	-	28.7	-	27.4	-	26.5	-

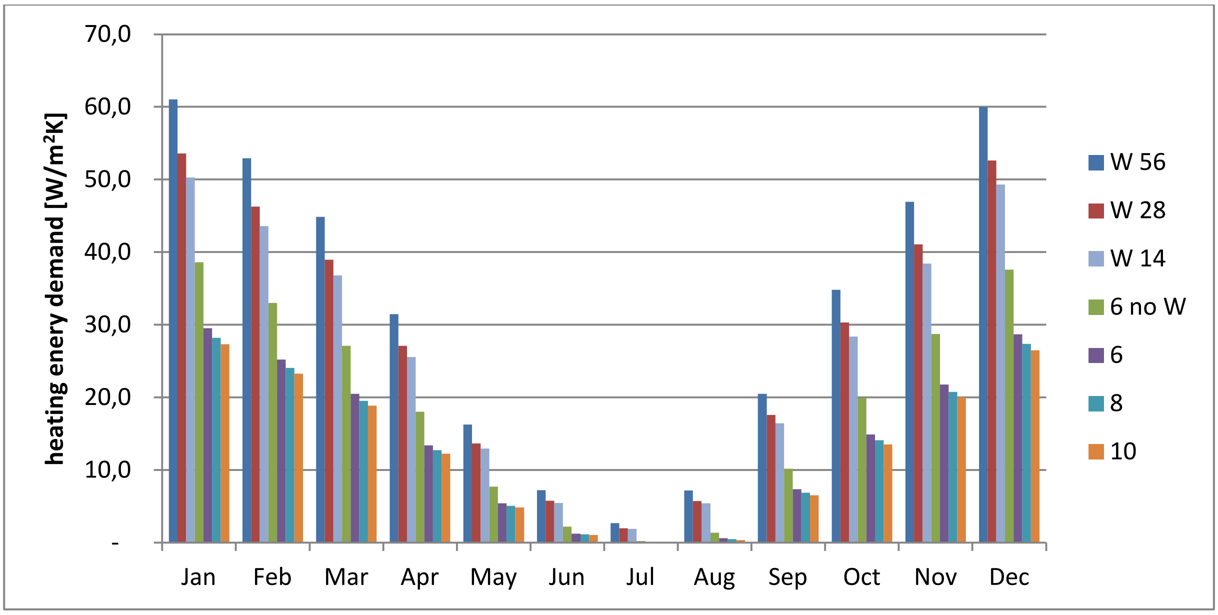
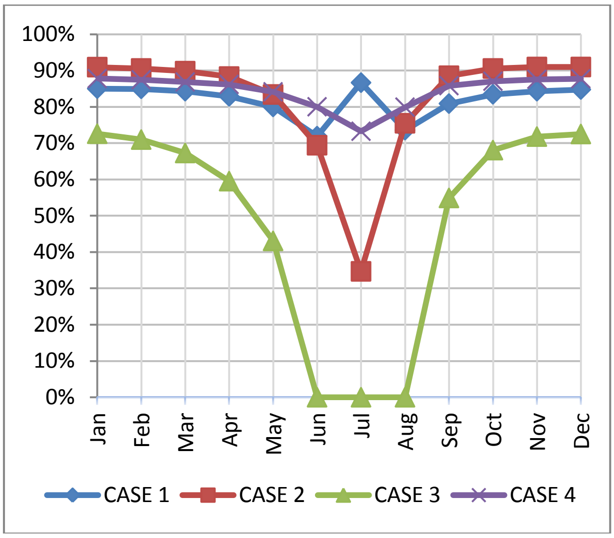


Figure 4.26. CASE 4-Energy demands before and after renovation in Helsinki weather conditions

In Table 4.37 a comparison among all the actions considered is shown. The reduction of the heating energy demand is presented as a percentage of the value of the not retrofitted building (action 0), for each one of the cases studied.

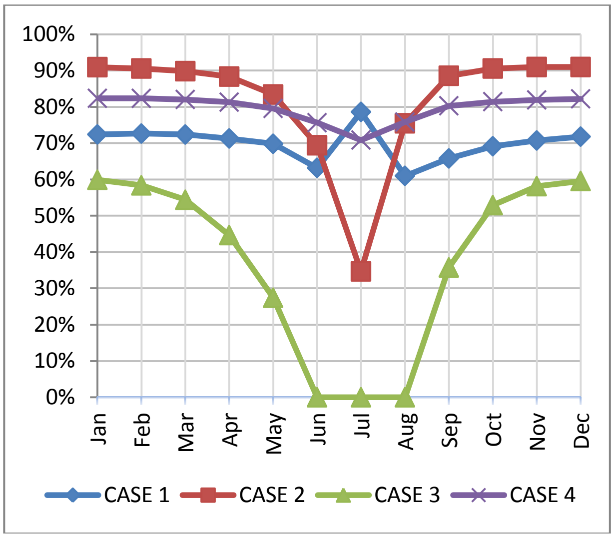
Table 4.37. Percentage of reduction of the heating energy demand for each action, Helsinki

ACTION 1

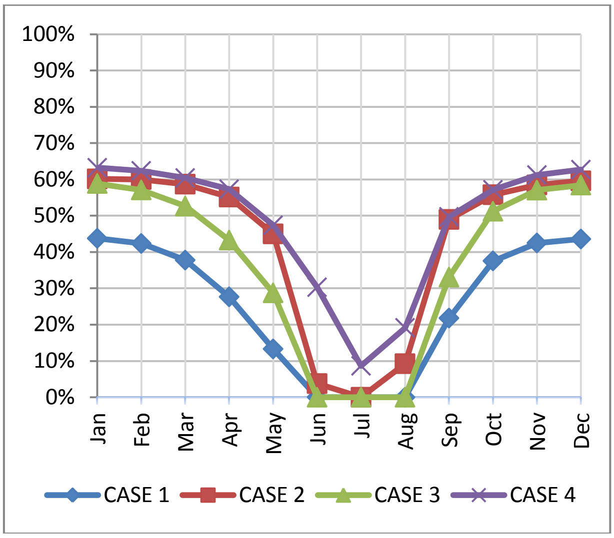


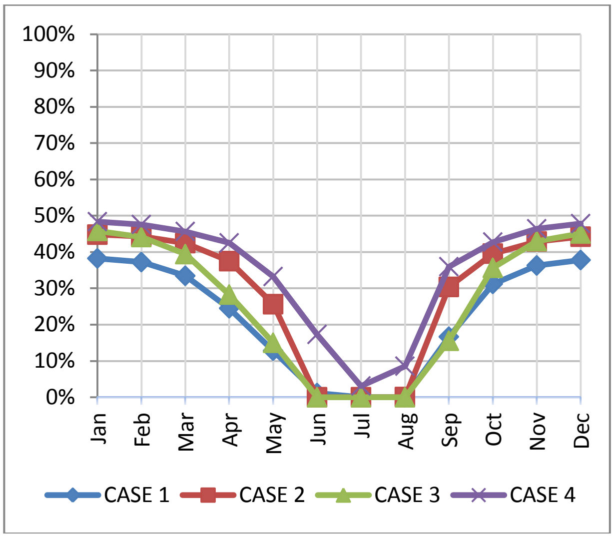
ACTION 3

ACTION 2

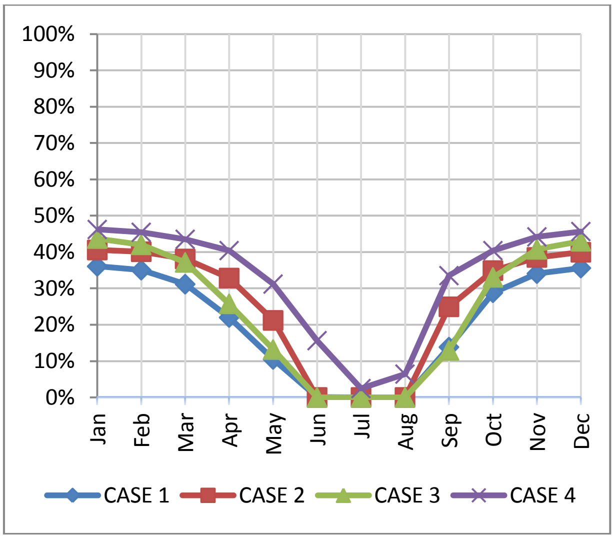


ACTION 4





ACTION 5



4.5 Redevelopment of the HVAC system – methods

The third phase of the analysis has been focused on the evaluation of several configuration for the HVAC. Integrated multi-energy systems have been studied in order to find the optimum configuration according to the energy demand of the case studies and the weather conditions of the selected places.
Every configuration has been tested on each case study and on each climate by the means of a dynamic simulation ran with the commercial code TRNSYS.
The Table 4.38 resumes the configurations analyzed. There are five configuration after the redevelopment of the HVAC system, and one configuration which is intended to be the standard for the before renovation equipment.

Table 4.38. Retrofitting configurations for the redevelopment of the HVAC system

HVAC SYSTEM REDEVELOPMENT – RETROFITTING CONFIGURATIONS	
CONFIGURATION 0	Heating: Regular gas-fired boiler, saled combustion chamber Conditioning : split-system single-zone air conditioning

	VMC with heat recovery (50% eficiency) No use of renewables resources Radiators
CONFIGURATION 1	Heating:Condensation gas boiler, air-water heat pump, Cooling: air-water heat pup, reversed operation VMC with heat recovery (90% eficiency) Solar collectors for DHW gneration Radiant floor panels
CONFIGURATION 2	Heating:Condensation gas boiler, water-water heat pump, Cooling: air-water chiller VMC with heat recovery (90% eficiency) Solar collectors for DHW gneration Radiant floor panels
CONFIGURATION 3	Heating: condensation gas boiler Cooling: air water chiller VMC with heat recovery (90% eficiency) Solar collectors for DHW gneration Fancoils
CONFIGURATION 4	Heating: condensation gas boiler Cooling: air water chiller VMC with heat recovery (90% eficiency) Solar collectors for DHW gneration Radiators
CONFIGURATION 5	Heating: pellet-fired boiler Cooling: air-water chiller VMC with heat recovery (90% eficiency) Solar collectors for DHW gneration Radiators

The objective of the study is to perform a comparison among different configuration of HVAC systems. It has to be noticed that involving different energy sources make necessary to analyze the energy consumption in terms of primary energy. Otherwise it would not be possible to compare the energy generated by different generators, for example the one produced by a gas boiler with the one delivered by an heat pump. Coefficients of conversion for thermal and electrical energy into primary energy have been introduced, and they are presented in Table 4.39.

Table 4.39. Coefficients for the conversion into primary energy

COEFFCIENTS OF CONVERSION INTO PRIMARY ENERGY				
Thermal Energy by fossil fuels	1 kWht	>>	1.1	kWhp
Solar thermal Energy	1 kWht	>>	0	kWhp
Thermal Energy by pellet combustion	1 kWhe	>>	0.3	kWhp
Electrical energy	1 kWhe	>>	2.3	kWhp

4.5.1 Configuration 0

The standard, assumed for the conditions before the redevelopment of the HVAC system, is a regular gas-fired boiler for heating and the generation of the DHW. No renewable resources are involved and none solar collector systems is consider as integration for the energy demand for DHW. According to the cooling energy demand, it has been satisfied by the means of single –zone air conditioning split-systems, technical features are shown in
Table 4.40.

For every case study a centralized heating systems has been considered, while the cooling energy demand is provided by several units placed in the occupied zones of the building. In order to esteem correctly the effect of the plant redevelopment, in the configuration 0 also a VMC has been considered, equipped with a heat recovery device with an efficiency of 50%.

Table 4.40. Technical features of air conditioning system

AIR CONDITIONING SPLIT-SYSTEMS		125 R WDD
Declared power	kW	2.7
Minimum air flow	m3/h	330
Average air flow	m3/h	390
Maximum air flow	m3/h	450
Electrical power	W	18

Table 4.41. Technical features of regular gas-fired boiler

GAS FIRED REGULAR BOILER		30/130 TS
Thermal power	kW	29,4
Lower thermal power	kW	11,7
Efficiency @ 100%		93,1%
Efficiency @ 30%		91,7%
Declared standard efficiency (CEE 92/42)		***
NOx Class		3
Electrical power	W	180
HEATING		
Max operative pressure	bar	3
Max opertaive Temperature	°C	85
Bolier water capacity	l	15
Heating temperature regulation	°C	40/80
Pressure	bar	1
DHW		
Maximun pressure	bar	7
Water flow EN 625	l/min	18,8
Water flow Dt 30°C	l/h	700
DHW Boiler capacity	l	130

The technical features of the boiler are presented in Table 4.41. To meet the energy demands of every case study one or more boilers have been considered in a parallel functioning. Proper value for the delivery and emission efficiency of the plant have been considered. This configuration considers a standard boiler, without any water tank, and radiators so the delivery and emission efficiency has been set to 0.945[11][8]. Regarding the cooling energy demand a delivery and emission efficiency value equal to 0.955 has been assumed, considering the use of single zone air conditioning devices.

4.5.2 Configuration 1

The first configuration considered for the redevelopment of the HVAC system is an integrated multi-energy plant where several energy generator are combined together to supply the heating and cooling energy demand. The idea is to use every source until it is the most convenient in terms of energy efficiency. The combination of an air-water heat pump with a gas condensing boiler allows the first to

[11] The standard UNI TS 11300:2 gives proper indication on the way the efficiency values of emission, regulation and energy delivery should be evaluated.The indicate value cames from the standard procedure.

work until the external conditions (dry bulb air temperature and relative humidity) guarantee an efficient functioning, then the latter is called in an independent or combined functioning searching for the minimum primary energy consumption.
The technical features of the condensing boiler used in the analysis are presented in Table 4.42 for the cases 3 and 4 and in Table 4.43 for the case studies 1 and 2. The technical feature of the air-water heat pump used in the models are shown in Table 4.44. The small one is used in case 1 and 2 and the second one in case 3 and 4. When it was necessary due to the increasing in the energy demand two or three devices have been considered in combined functioning. Radiant floor panels have been chosen as heating delivery devices for all the case studied, delivery and emission efficiency value has been set equal to 0.988.
Solar thermal collectors have been considered as heat provider for the DHW generation. It has been considered the possibility of providing, with solar energy, an integration to heating energy demands as well. But on the basis of previous analysis, that seemed not to be convenient. In fact, the poor contribution to the heating energy supply don't justified the complexity introduced in the plant by the connection of the solar system within the heating section. The technical features about the solar collectors are resumed in Table 4.45, while the parameters regarding their efficiency are presented in Table 46.

Table 4.42. Tecnical features of the condensing boiler (case 3,4)

GAS FIRED CONDENSING BOILER		**ME 100**
Thermal power	kW	93.6 (2x46.8)
Lower thermal power	kW	10.5
Efficiency @ 30%/100% (80-60)		96.9% / 97.5%
Efficiency @ 30%/100% (50-30)		109.0% / 106.7%
Declared standard efficiency (CEE 92/42)		****
NOx Class		5
Electrical power	W	360
Max operative pressure	bar	3.5
Max opertaive Temperature	°C	85
Bolier water capacity	l	4.6
Heating temperature regulation	°C	20/80
Pressure	bar	1

Table 4.43. Tecnical features of the condensing boiler (case 1,2)

GAS FIRED CONDENSING BOILER		**ME 35**
Thermal power	kW	33.8
Lower thermal power	kW	3.7
Efficiency @ 30%/100% (80-60)		92.0% / 97.2%
Efficiency @ 30%/100% (50-30)		106.3% / 106.8%
Declared standard efficiency (CEE 92/42)		****
NOx Class		5
Electrical power	W	140
Max operative pressure	bar	3.5
Max opertaive Temperature	°C	85
Bolier water capacity	l	4.6
Heating temperature regulation	°C	20/80
Pressure	bar	1

Table 4.44. Technical features of the air-water heat pumps

		HP012 - R410A		**HP033 - R410A**	
Compressor frequency	[Hz]	30	110	30	120

Cooling @ 35°C air 12/7°C water					
Cooling power	[kW]	3,1	11,3	6,1	32,2
Compressor auxiliary energy	[kW]	0,6	3,1	1,4	10,9
Fans auxiliary energy	[kW]	0,16	0,16	0,32	0,32
Pumps auxilay energy	[kW]	0,07	0,07	0,31	0,31
EER		3,78	3,49	3,22	2,91
Water flow	[kg/h]	525	1946	1056	5545
Air flow	[m3/h]	7000	7000	14000	14000
Cooling @ 35°C air 23/18°C water					
Cooling power	[kW]	4,0	15,8	12,8	44,5
Compressor auxiliary energy	[kW]	0,6	3,2	2,1	11,6
Fans auxiliary energy	[kW]	0,16	0,16	0,32	0,32
Pumps auxilay energy	[kW]	0,07	0,07	0,31	0,31
EER		5,20	4,65	5,23	3,76
Water flow	[kg/h]	696	2721	2204	7663
Air flow	[m3/h]	7000	7000	14000	14000
Heating BT @ 40/45°C e 7°C ext.air					
Heating power	[kW]	3,0	11,9	9,6	35,8
Compressor auxiliary energy	[kW]	0,7	3,3	2,3	10,9
Fans auxiliary energy	[kW]	0,16	0,16	0,32	0,32
Pumps auxilay energy	[kW]	0,07	0,07	0,31	0,31
COP		3,20	3,41	3,46	3,23
Water flow	[kg/h]	511	2049	1657	6165
Air flow	[m3/h]	7000	7000	14000	14000
Heating BT @ 30/35°C e 7°C ext. air					
Heating power	[kW]	3,2	12,5	10,1	36,4
Compressor auxiliary energy	[kW]	0,6	2,7	1,9	9,0
Fans auxiliary energy	[kW]	0,16	0,16	0,32	0,32
Pumps auxilay energy	[kW]	0,07	0,07	0,31	0,31
COP		4,00	4,33	4,31	3,97
Water flow	[kg/h]	542	2153	1739	6268
Air flow	[m3/h]	7000	7000	14000	14000

Table 4.45. Technical features of the solar collectors

VACUUM HEAT PIPE SOLAR COLLECTOR			
Number of tubes	20	Fluid content	0.9 l
Diametre of tubes	65 mm	Flow rate regulation	60 - 250 l/h
Glass thickness	1.7 mm	Tested flow rate	160 l/h
Length	2.0 m	Absorber element	copper sheet
Width	1.452 m	Absorber lengh	1.730.0 m
Heigth	0.165 m	Absorber width	58.0 mm
Coefficient of absorption	> 95%	Absorber thickness	0.15 mm
Coefficient of emission	< 5%	Selective covering	titanium oxide
Gross area	2.904 m²	Max operative temperature	150°C
Aperture area	2.270 m²	Max operative pressure	6 bar
Absorption area	1.984 m²	Absorption element	copper sheet
Weight	49.5 kg		

Table 46. Parameters of performance of the solar collectors

	Absorber area	**Aperture area**	**Gross area**
η_0 optical efficiency	0.812	0.710	0.555
a1 (W/m2K2)	1.43	1.25	0.98
a2 (W/m2K2)	0.0051	0.0045	0.0035

Heat storage have been need to collect the thermal energy given by the different generators. In the case 1 and 2 a single storage tank has been considered. It is a storage with a capacity of 500 litres, provided with two coiled heat exchangers, one placed in the upper part of the tank and linked to the boiler and the second placed in the bottom part of the tank and connected to the solar system. Three ports (a port refers to a pair of inlet and outlet) allow the connection to the heat pump and to the delivery circuits for heating and DHW. in case 3 and 4 three storages are implemented in the model, one dedicated to the heating section and two to the DHW generation.
The storages implemented in the case studies 3 and 4 are more complex. The storage for the heating section of the plant has a capacity of 800 litres, and it has not provided with heat exchangers. The boiler circuit as well as the one of the heat pump is connected to the tank by the means of a port, and also the pipes of the heating circuit are direct connect to the storage.
The tanks dedicated to the DHW generation have a capacity of 2000 litres each. They have a port connected with the boiler and a coiled heat exchanger connected to the solar collectors circuit. A second coiled heat exchanger is used to provide the DHW generation. Water from the aqueduct comes in from the bottom of the storage and trough the coil crosses all the tank until the outlet, where it is mixed with a proper quantity of cold water and the delivered to the users.
Controlled mechanical ventilation has also been implemented, in order to guarantee a proper quality of the indoor environment, the air flow change was set to 0.56 V/h. Heat recovery systems have been implemented with an efficiency of about 90%.

4.5.3 Configuration 2

The second configuration a differs from the former in the choose of the heat pump. A water heat pump has been selected and the cooling energy demand has been satisfied by the means of an air-water chiller. Technical features of the selected machines are provided below.
With the exception of the choose of the heat pump and the cooling devices the rest of the plant is equal to the configuration number 1.

Table 4.47. Technical features of the chiller used in Cases 1 and 2

CHILLER 008 - R410A		
Cooling @ 35°C air 12/7°C water Cooling power	[kW]	7.8
auxiliary energy	[kW]	1.98
EER		3.95
Water flow	[kg/h]	590
Air flow	[m3/h]	6300

Table 4.48. Technical features of the chiller used in Cases 3 and 4

CHILLER 020 - R410A		
Cooling @ 35°C air 12/7°C water Cooling power	[kW]	34.4
auxiliary energy	[kW]	5.6
EER		6.15
Water flow	[kg/h]	5900
Air flow	[m3/h]	13500

Table 4.49. Technical features of the water heat pump used in Cases 1 and 2

WATER HEAT PUMP 040 - R410A		
Heating power 40/45°C water 10/7°C water	[kW]	12.56
auxiliary energy	[kW]	3.14
COP		4.01
Water flow condenser	[kg/h]	2838
Water flow evaporator	[kg/h]	2746

Table 4.50. Technical features of the water heat pump used in Cases 3 and 4

WATER HEAT PUMP - R410A		
Compressor frequency	[Hz]	50
Heating @ 40/45°C water 10/7°C water Cooling power	[kW]	55
auxiliary energy	[kW]	13
EER		4.2
Water flow condenser	[kg/h]	6500
Water flow evaporator	[kg/h]	6300

4.5.4 Configuration 3

The configuration number 3 considers a gas condensing boiler as heat generator. Unlike the former solutions, this plant is not equipped with any heat pump and as heat delivery systems fan coils have been chosen instead of radiant panels, so the delivery and emission efficiency value is equal to 0.955. During the heating season the boiler set temperature is fixed to 70 °C, and the operative temperature of the fan coils is set equal to 60 °C. Technical features of the boilers are provided in Table 4.42 and in Table 4.43.

4.5.5 Configuration 4

The configuration number 4 is identical to the number 3. The only difference is represented by the heat delivery facilities that in this solution are traditional cast-iron radiators; the delivery and emission efficiency value is equal to 0.945. As in the former configuration, during the heating season the boiler set temperature is fixed to 70 °C, and the operative temperature of the fan coils is set equal to 60 °C.

4.5.6 Configuration 5

The last configuration analyzed is equal to the plant solution number 3. The difference between them is represented by the choice of a pellet fired boiler, technical features are provided in

Table 4.51 and in Table 4.52. According to the energy demand of each case study one or more boiler have been combined to meet the user needs.

The conversion of the energy supplied by the combustion of pellet into primary energy has been done considering a coefficient of 0.7. That means that for every kWh generated by the pellet fired boiler only the 70% have been considered renewable energy, the other 30% is converted as generated by fossil fuel [9]. Traditional cast-iron radiators have been considered and the delivery and emission efficiency value has been set equal to 0.945.

Table 4.51. Tecnical features of the pellet fired boiler (case 1,2)

PELLET FIRED BOILER		300-P
Thermal power	kW	24
Lower thermal power	kW	8
Efficiency @ 30%/100% (75-60)		95.3 / 94.5%
Declared standard efficiency (CEE 92/42)		***
NOx Class		3
Electrical power shich on	W	370
Electrical power heating program	W	95
Electrical power pellet charging	W	1960
Max operative pressure	bar	3
Max opertaive Temperature	°C	75
Bolier water capacity	l	180
Heating temperature regulation	°C	60/75
Pressure	bar	1

Table 4.52. Tecnical features of the pellet fired boiler (case 3,4)

PELLET FIRED BOILER		300-P
Thermal power	kW	48
Lower thermal power	kW	16
Efficiency @ 30%/100% (75-60)		95.8 / 94.2%
Declared standard efficiency (CEE 92/42)		***
NOx Class		3
Electrical power shich on	W	400
Electrical power heating program	W	120
Electrical power pellet charging	W	1960
Max operative pressure	bar	3
Max opertaive Temperature	°C	75
Bolier water capacity	l	180
Heating temperature regulation	°C	60/75
Pressure	bar	1

4.6 Redevelopment of the HVAC system – results

The results of the redevelopment of the HVAC system are presented in the following paragraphs. The analysis has considered four examples of building, tested in four weather conditions and equipped with five different configurations for the HVAC system. That means that eighty simulations have been carried out to obtain the most possible complete analysis of the performance of the plant on the basis of the users energy needs, of the status of the building and of the climate.

The results are classified by building case studies, then into every section they are divided by weather condition. In fact, in this way, it has seemed to be easier to focus on the different performance of each HVAC configurations.

4.6.1 CASE 1

4.6.1.1 Athens

The energy demands of the case study 1 in the weather conditions of Athens are presented in Table 4.53. The Table 4.54 presents the primary energy demand of the Configuration 0.

The results obtained by the Configuration number 1 are shown in Table 4.55 while the one of the Configuration number 2 in
Table 4.56. These configurations consider a gas condensing boiler, coupled to a heat pump, air condensed in the first and water condensed in the second one. The heat and cold are delivered by the means of floor radiant systems. The results of the configuration 3 and 4 are presented Table 4.57 and Table 4.58. The plant contains a gas condensing boiler and the a solar thermal system, none heat pump is presented and the delivery systems are an coils in the first configuration and radiators in the second one. The configuration 5 considers a pellet fired boiler and solar collectors. The delivery systems consists in standard iron-cast radiators. The cooling energy demand is satisfied by the heat pump in reverse functioning in the configuration number 1 and by an air-water chiller in the other ones.

Table 4.53. Total energy demand – Case 1- Athens

ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	1'815.1	14.4	105.9
COOLING	5'256.3	41.7	
DHW	2'984.9	23.7	
VMC_H - heat recovery efficiency 0.5	405.3	3.2	
VMC_C- heat recovery efficiency 0.5	2'886.5	22.9	

Table 4.54. Primary energy demand - Case 1 – Athens – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	2'112.3	16.8	**87.4**
DHW	5'408.3	42.9	
COOLING	2'219.3	17.6	
VMC_H - heat recovery efficiency 0.5	1'272.9	10.1	

Table 4.55. Primary energy demand - Case 1 – Athens – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	105.0
HEATING + tank losses	4.4	16.1	-	20.6	
DHW	10.0	-	15.1	25.1	
COOLING	-	44.8	-	44.8	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**72.1**
HEATING	5.4	22.9	-	28.3	
DHW	12.1	-	-	12.1	
COOLING	-	23.0	-	23.0	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**18%**

Table 4.56. Primary energy demand - Case 1 – Athens – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	105.0
HEATING + tank losses	4.7	15.9	-	20.6	
DHW	10.0	-	15.1	25.1	

COOLING	-	44.8	-	44.8	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWh/m^{2}y]	BOILER	HP	SOLAR	TOTAL	
HEATING	5.6	13.8	-	19.5	**60.2**
DHW	12.1	-	-	12.1	
COOLING	-	20.6	-	20.6	
VMC (heat recovery 90% eff.)	2.2	5.9	-	8.0	
PRIMARY ENERGY REDUCTION respect to configuration 0					**31%**

Table 4.57. Primary energy demand - Case 1 – Athens – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	22.1	-	-	22.1	108.9
DHW	10.7	-	15.4	26.0	
COOLING	-	46.3	-	46.3	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWh/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	26.7	-	-	26.7	**72.0**
DHW	12.9	-	-	12.9	
COOLING	-	23.7	-	23.7	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**18%**

Table 4.58. Primary energy demand - Case 1 – Athens – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	22.5	-	-	22.5	109.5
DHW	10.8	-	15.0	25.8	
COOLING	-	46.7	-	46.7	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWh/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	27.2	-	-	27.2	**73.0**
DHW	13.1	-	-	13.1	
COOLING	-	24.0	-	24.0	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**16%**

Table 4.59. Primary energy demand - Case 1 – Athens – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	108.7
HEATING + tank losses	22.3	-	-	22.3	
DHW	10.6	-	15.0	25.6	

COOLING	-	46.3	-	46.3	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWh/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	7.9	-	-	7.9	**42.5**
DHW	3.7	-	-	3.7	
COOLING	-	23.7	-	23.7	
VMC (heat recovery 90% eff.)	0.6	6.5	-	7.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**51%**

4.6.1.2 Venice

The energy demands of the case study 1 in the weather conditions of Venice are presented in the following Tables.

Table 4.60. Total energy demand – Case 1- Venice

ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	4'865.5	38.6	104.6
COOLING	3'189.1	25.3	
DHW	2'282.5	18.1	
VMC_H - heat recovery efficiency 0.5	1'095.4	8.7	
VMC_C - heat recovery efficiency 0.5	1'752.1	13.9	

Table 4.61. Primary energy demand - Case 1 – Venice – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	5'662.0	44.9	**121.3**
DHW	5'408.3	42.9	
COOLING	2'219.3	17.6	
VMC_H - heat recovery efficiency 0.5	2'000.5	15.9	

Table 4.62. Primary energy demand - Case 1 – Venice – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	8.9	36.8	-	45.7	104.2
DHW	9.1	-	10.0	19.0	
COOLING	-	26.9	-	26.9	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY kWhp/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	10.8	28.3	-	39.1	**76.1**
DHW	10.9	-	-	10.9	
COOLING	-	15.7	-	15.7	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**37%**

Table 4.63. Primary energy demand - Case 1 – Venice – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	5.7	40.1	-	45.7	104.3
DHW	9.7	-	9.3	19.0	
COOLING	-	27.0	-	27.0	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	6.8	24.1	-	30.9	**63.9**
DHW	11.8	-	-	11.8	
COOLING	-	11.9	-	11.9	
VMC (heat recovery 90% eff.)	5.8	3.4	-	9.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**47%**

Table 4.64. Primary energy demand - Case 1 – Venice – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	49.5	-	-	49.5	110.1
DHW	9.7	-	10.2	19.9	
COOLING	-	28.1	-	28.1	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	59.9	-	-	59.9	**98.4**
DHW	11.8	-	-	11.8	
COOLING	-	16.4	-	16.4	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**19%**

Table 4.65. Primary energy demand - Case 1 – Venice – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	50.5	-	-	50.5	111.1
DHW	9.7	-	10.1	19.7	
COOLING	-	28.3	-	28.3	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	61.1	-	-	61.1	**99.6**
DHW	11.7	-	-	11.7	
COOLING	-	16.6	-	16.6	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**18%**

Table 4.66. Primary energy demand - Case 1 – Venice – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	50.1	-	-	50.1	110.4
DHW	10.2	-	9.5	19.7	
COOLING	-	28.1	-	28.1	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	17.7	-	-	17.7	**43.9**
DHW	3.6	-	-	3.6	
COOLING	-	16.4	-	16.4	
VMC (heat recovery 90% eff.)	1.7	4.5	-	6.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**64%**

4.6.1.3 Budapest

The energy demands of the case study 1 in the weather conditions of Budapest are presented in the following Tables.

Table 4.67. Total energy demand – Case 1- Budapest

ENERGY DEMAND	**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING	6'920.1	54.9	118.8
COOLING	2'004.2	15.9	
DHW	2'467.1	19.6	
VMC_H - heat recovery efficiency 0.5	1'564.8	12.4	
VMC_C - heat recovery efficiency 0.5	2'016.8	16.0	

Table 4.68. Primary energy demand - Case 1 – Budapest – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING	8'053.0	63.9	**147.2**
DHW	5'408.3	42.9	
COOLING	2'219.3	17.6	
VMC_H - heat recovery efficiency 0.5	2'873.0	22.8	

Table 4.69. Primary energy demand - Case 1 – Budapest – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	13.8	50.2	-	64.1	117.7
DHW	9.1	-	11.6	20.7	
COOLING	-	17.1	-	17.1	
VMC (heat recovery 90% eff.)	6.9	8.9		15.8	

PRIMARY ENERGY kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	16.7	48.8	-	65.5	**104.1**
DHW	11.0	-	-	11.0	

COOLING	-	12.6	-	12.6	
VMC (heat recovery 90% eff.)	8.3	6.6	-	14.9	
PRIMARY ENERGY REDUCTION respect to configuration 0					**29%**

Table 4.70. Primary energy demand - Case 1 – Budapest – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	7.5	56.6	-	64.1	117.7
DHW	8.9	-	11.8	20.7	
COOLING	-	17.1	-	17.1	
VMC (heat recovery 90% eff.)	6.9	8.9		15.8	
PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	9.1	24.1	-	30.9	
DHW	10.8	-	-	11.8	**74.2**
COOLING	-	11.9	-	11.9	
VMC (heat recovery 90% eff.)	8.3	3.4	-	9.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**50%**

Table 4.71. Primary energy demand - Case 1 – Budapest – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	68.7	-	-	68.7	123.7
DHW	9.0	-	12.5	21.5	
COOLING	-	17.6	-	17.6	
VMC (heat recovery 90% eff.)	6.9	8.9		15.8	
PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	83.1	-	-	83.1	
DHW	10.9	-	-	10.9	**122.0**
COOLING	-	13.1	-	13.1	
VMC (heat recovery 90% eff.)	8.3	6.6	-	14.9	
PRIMARY ENERGY REDUCTION respect to configuration 0					**17%**

Table 4.72. Primary energy demand - Case 1 – Budapest – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	70.1	-	-	70.1	125.0
DHW	9.0	-	12.4	21.3	
COOLING	-	17.8	-	17.8	
VMC (heat recovery 90% eff.)	6.9	8.9		15.8	
PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	84.7	-	-	84.7	**123.6**
DHW	10.8	-	-	10.8	

COOLING	-	13.2	-	13.2	
VMC (heat recovery 90% eff.)	8.3	6.6	-	14.9	
PRIMARY ENERGY REDUCTION respect to configuration 0					**16%**

Table 4.73. Primary energy demand - Case 1 – Budapest – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	69.4	-	-	69.4	124.2
DHW	9.4	-	11.9	21.3	
COOLING	-	17.6	-	17.6	
VMC (heat recovery 90% eff.)	6.9	8.9		15.8	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	24.5	-	-	24.5	**49.9**
DHW	3.3	-	-	3.3	
COOLING	-	13.1	-	13.1	
VMC (heat recovery 90% eff.)	2.4	6.6	-	9.0	
PRIMARY ENERGY REDUCTION respect to configuration 0					**66%**

4.6.1.4 Helsinki

The energy demands of the case study 1 in the weather conditions of Helsinki are presented in the following Tables.

Table 4.74. Total energy demand – Case 1- Helsinki

ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		11'823.5	93.8	152.64
COOLING		983.2	7.8	
DHW		2'878.5	22.8	
VMC_H -	heat recovery efficiency 0.5	2'661.8	21.1	
VMC_C-	heat recovery efficiency 0.5	893.6	7.1	

Table 4.75. Primary energy demand - Case 1 – Helsinki – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		13'759.1	109.2	**201.2**
DHW		5'408.3	42.9	
COOLING		2'219.3	17.6	
VMC_H -	heat recovery efficiency 0.5	3'980.2	31.6	

Table 4.76. Primary energy demand - Case 1 – Helsinki – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	22.9	83.0	-	105.8	154.1
DHW	14.4	-	9.8	24.2	
COOLING	-	8.4	-	8.4	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	27.6	90.9	-	118.5	**159.2**
DHW	17.4	-	-	17.4	
COOLING	-	6.2	-	6.2	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**21%**

Table 4.77. Primary energy demand - Case 1 – Helsinki – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	12.4	93.4	-	105.8	154.1
DHW	16.7	-	7.5	24.2	
COOLING	-	8.4	-	8.4	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	15.0	68.8	-	83.8	**123.1**
DHW	20.2	-	-	20.2	
COOLING	-	3.5	-	3.5	
VMC (heat recovery 90% eff.)	14.2	1.6	-	15.8	
PRIMARY ENERGY REDUCTION respect to configuration 0					**39%**

Table 4.78. Primary energy demand - Case 1 – Helsinki – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	108.4	-	-	108.4	156.7
DHW	13.6	-	10.4	24.0	
COOLING	-	8.7	-	8.7	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	131.0	-	-	83.1	**171.0**
DHW	16.5	-	-	10.9	
COOLING	-	13.1	-	13.1	
VMC (heat recovery 90% eff.)	14.2	6.6	-	14.9	
PRIMARY ENERGY REDUCTION respect to configuration 0					**15%**

Table 4.79. Primary energy demand - Case 1 – Helsinki – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	109.5	-	-	109.5	157.9
DHW	13.6	-	10.4	24.0	
COOLING	-	8.7	-	8.7	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	132.4	-	-	132.4	**172.4**
DHW	16.5	-	-	16.5	
COOLING	-	6.5	-	6.5	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**14%**

Table 4.80. Primary energy demand - Case 1 – Helsinki – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	109.5	-	-	109.5	157.8
DHW	14.3	-	9.7	24.0	
COOLING	-	8.7	-	8.7	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	38.6	-	-	38.6	**57.2**
DHW	5.0	-	-	5.0	
COOLING	-	6.4	-	6.4	
VMC (heat recovery 90% eff.)	4.1	2.9	-	7.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**72%**

4.6.2 CASE 2

4.6.2.1 Athens

The energy demands of the case study 2 in the weather conditions of Athens are presented in the following Tables.

Table 4.81. Total energy demand – Case 2- Athens

ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	7'077.0	33.7	101.1
COOLING	6'762.0	32.2	
DHW	1'898.3	9.0	
VMC_H - heat recovery efficiency 0.5	675.2	3.2	
VMC_C- heat recovery efficiency 0.5	4'808.9	22.9	

Table 4.82. Primary energy demand - Case 2 – Athens – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	8'235.5	39.2	**109.8**
DHW	9'010.2	42.9	
COOLING	3'697.3	17.6	
VMC_H - heat recovery efficiency 0.5	2'120.7	10.1	

Table 4.83. Primary energy demand - Case 2 – Athens – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	8.9	30.4	-	39.3	97.9
DHW	3.8	-	5.7	9.6	
COOLING	-	34.6	-	34.6	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	10.2	43.6	-	53.9	**84.9**
DHW	4.6	-	-	4.6	
COOLING	-	17.7	-	17.7	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**23%**

Table 4.84. Primary energy demand - Case 2 – Athens – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	8.9	30.4	-	39.3	97.9
DHW	3.8	-	5.7	9.6	
COOLING	-	34.6	-	34.6	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	10.7	26.4	-	37.1	**65.7**
DHW	4.6	-	-	4.6	
COOLING	-	15.9	-	15.9	
VMC (heat recovery 90% eff.)	2.2	5.9	-	8.0	
PRIMARY ENERGY REDUCTION respect to configuration 0					**40%**

Table 4.85. Primary energy demand - Case 2 – Athens – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	42.1	-	-	42.1	102.3
DHW	4.1	-	5.9	9.9	
COOLING	-	35.7	-	35.7	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	50.9	-	-	50.9	**82.9**
DHW	4.9	-	-	4.9	
COOLING	-	18.3	-	18.3	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**25%**

Table 4.86. Primary energy demand - Case 2 – Athens – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	42.9	-	-	42.9	103.4
DHW	4.1	-	5.7	9.9	
COOLING	-	36.1	-	36.1	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	51.9	-	-	51.9	**84.1**
DHW	5.0	-	-	5.0	
COOLING	-	18.5	-	18.5	
VMC (heat recovery 90% eff.)	2.2	6.5	-	8.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**23%**

Table 4.87. Primary energy demand - Case 2 – Athens – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	42.6	-	-	42.6	102.6
DHW	4.1	-	5.7	9.8	
COOLING	-	35.7	-	35.7	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	15.0	-	-	15.0	**41.9**
DHW	1.4	-	-	1.4	
COOLING	-	18.3	-	18.3	
VMC (heat recovery 90% eff.)	0.6	6.5	-	7.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**62%**

4.6.2.2 Venice

The energy demands of the case study 2 in the weather conditions of Venice are presented in the following Tables.

Table 4.88. Total energy demand – Case 2- Venice

ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		14'238.0	67.8	117.7
COOLING		3'444.0	16.4	
DHW		2'282.5	10.9	
VMC_H -	heat recovery efficiency 0.5	1'824.9	8.7	
VMC_C-	heat recovery efficiency 0.5	2'919.0	13.9	

Table 4.89. Primary energy demand - Case 2 – Venice – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	16'568.8	78.9	155.3
DHW	9'010.2	42.9	
COOLING	3'697.3	17.6	
VMC_H - heat recovery efficiency 0.5	3'332.8	15.9	

Table 4.90. Primary energy demand - Case 2 – Venice – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	14.6	60.3	-	74.9	116.3
DHW	5.4	-	6.0	11.4	
COOLING	-	17.4	-	17.4	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	17.7	46.3	-	64.0	**91.1**
DHW	6.6	-	-	6.6	
COOLING	-	10.2	-	10.2	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**41%**

Table 4.91. Primary energy demand - Case 2 – Venice – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	9.3	40.1	-	45.7	116.4
DHW	5.9	-	9.3	19.0	
COOLING	-	27.0	-	27.0	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	11.2	39.4	-	50.6	**74.7**
DHW	7.1	-	-	7.1	
COOLING	-	7.7	-	7.7	
VMC (heat recovery 90% eff.)	5.8	3.4	-	9.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**52%**

Table 4.92. Primary energy demand - Case 2 – Venice – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	81.1	-	-	81.1	123.8
DHW	5.8	-	6.1	12.0	
COOLING	-	18.2	-	18.2	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	98.1	-	-	98.1	126.1
DHW	7.1	-	-	7.1	
COOLING	-	10.6	-	10.6	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**19%**

Table 4.93. Primary energy demand - Case 2 – Venice – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	82.7	-	-	82.7	125.5
DHW	5.8	-	6.0	11.8	
COOLING	-	18.4	-	18.4	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	100.0	-	-	100.0	128.1
DHW	7.0	-	-	7.0	
COOLING	-	10.7	-	10.7	
VMC (heat recovery 90% eff.)	5.8	4.5	-	10.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**18%**

Table 4.94. Primary energy demand - Case 2 – Venice – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	82.0	-	-	82.0	124.6
DHW	6.1	-	5.7	11.8	
COOLING	-	18.2	-	18.2	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWh/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	28.9	-	-	28.9	47.9
DHW	2.2	-	-	2.2	
COOLING	-	10.6	-	10.6	
VMC (heat recovery 90% eff.)	1.7	4.5	-	6.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**69%**

4.6.2.3 Budapest

The energy demands of the case study 2 in the weather conditions of Budapest are presented in the following Tables.

Table 4.95. Total energy demand – Case 2- Budapest

ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	19'005.0	90.5	134.1
COOLING	1'365.0	6.5	
DHW	2'467.1	11.7	
VMC_H - heat recovery efficiency 0.5	2'607.0	12.4	
VMC_C- heat recovery efficiency 0.5	2'721.6	13.0	

Table 4.96. Primary energy demand - Case 2 – Budapest – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	22'116.2	105.3	**187.5**
DHW	9'010.2	42.9	
COOLING	3'697.3	17.6	
VMC_H - heat recovery efficiency 0.5	4'558.0	21.7	

Table 4.97. Primary energy demand - Case 2 – Budapest – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	21.6	78.6	-	100.2	133.7
DHW	5.5	-	7.0	12.5	
COOLING	-	7.0	-	7.0	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	
PRIMARY ENERGY kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	26.2	76.4	-	102.5	**128.0**
DHW	6.6	-	-	6.6	
COOLING	-	5.2	-	5.2	
VMC (heat recovery 90% eff.)	8.3	5.3	-	13.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**32%**

Table 4.98. Primary energy demand - Case 2 – Budapest – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	11.7	88.5	-	100.2	133.7
DHW	5.4	-	7.1	12.5	
COOLING	-	7.0	-	7.0	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	
PRIMARY ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	14.2	54.3	-	68.5	**89.4**
DHW	6.5	-	-	6.5	

COOLING	-	3.0	-	3.0	
VMC (heat recovery 90% eff.)	8.3	3.1	-	11.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**52%**

Table 4.99. Primary energy demand - Case 2 – Budapest – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	107.5	-	-	107.5	141.8
DHW	5.4	-	7.5	12.9	
COOLING	-	7.2	-	7.2	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	130.0	-	-	130.0	
DHW	6.6	-	-	6.6	**155.5**
COOLING	-	5.3	-	5.3	
VMC (heat recovery 90% eff.)	8.3	5.3	-	13.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**17%**

Table 4100. Primary energy demand - Case 2 – Budapest – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	109.6	-	-	109.6	143.8
DHW	5.4	-	7.4	12.8	
COOLING	-	7.3	-	7.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	132.5	-	-	132.5	
DHW	6.5	-	-	6.5	**158.1**
COOLING	-	5.4	-	5.4	
VMC (heat recovery 90% eff.)	8.3	5.3	-	13.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**16%**

Table 4.101. Primary energy demand - Case 2 – Budapest – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	108.7	-	-	108.7	142.8
DHW	5.6	-	7.2	12.8	
COOLING	-	7.2	-	7.2	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	38.3	-	-	38.3	**53.4**
DHW	2.0	-	-	2.0	

COOLING	-	5.3	-	5.3	
VMC (heat recovery 90% eff.)	2.4	5.3	-	7.8	
PRIMARY ENERGY REDUCTION respect to configuration 0					**72%**

4.6.2.4 Helsinki

The energy demands of the case study 2 in the weather conditions of Helsinki are presented in the following Tables.

Table 4.102. Total energy demand – Case 2- Helsinki

ENERGY DEMAND		**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING		30'912.0	147.2	190.5
COOLING		294.0	1.4	
DHW		2'878.5	13.7	
VMC_H -	heat recovery efficiency 0.5	4'434.5	21.1	
VMC_C -	heat recovery efficiency 0.5	1'488.7	7.1	

Table 103. Primary energy demand - Case 2 – Helsinki – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING		35'972.5	171.3	**263.4**
DHW		9'010.2	42.9	
COOLING		3'697.3	17.6	
VMC_H -	heat recovery efficiency 0.5	6'631.0	31.6	

Table 4.104. Primary energy demand - Case 2– Helsinki – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	192.8
HEATING + tank losses	34.8	126.3	-	161.1	
DHW	8.6	-	5.9	14.5	
COOLING	-	1.5	-	1.5	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**209.0**
HEATING	42.1	138.3	-	180.4	
DHW	10.4	-	-	10.4	
COOLING	-	1.1	-	1.1	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**21%**

Table 4.105. Primary energy demand - Case 2 – Helsinki – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	192.8
HEATING + tank losses	18.8	142.3	-	161.1	
DHW	10.0	-	4.5	14.5	
COOLING	-	1.5	-	1.5	

VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	22.8	104.8	-	127.5	**156.1**
DHW	12.1	-	-	12.1	
COOLING	-	0.6	-	0.6	
VMC (heat recovery 90% eff.)	14.2	1.6	-	15.8	
PRIMARY ENERGY REDUCTION respect to configuration 0					**41%**

Table 4.106. Primary energy demand - Case 2 – Helsinki – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	165.0	-	-	165.0	196.6
DHW	8.2	-	6.2	14.4	
COOLING	-	1.6	-	1.6	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	199.4	-	-	199.4	**227.5**
DHW	9.9	-	-	9.9	
COOLING	-	1.2	-	1.2	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**14%**

Table 4.107. Primary energy demand - Case 2 – Helsinki – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	166.7	-	-	166.7	198.2
DHW	8.2	-	6.2	14.4	
COOLING	-	1.6	-	1.6	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	201.5	-	-	132.4	**229.6**
DHW	9.9	-	-	16.5	
COOLING	-	6.5	-	6.5	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**13%**

Table 4.108. Primary energy demand - Case 2 – Helsinki – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	166.7	-	-	166.7	198.3
DHW	8.6	-	5.8	14.4	
COOLING	-	1.6	-	1.6	

VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	58.8	-	-	58.8	
DHW	3.0	-	-	3.0	**70.1**
COOLING	-	1.2	-	1.2	
VMC (heat recovery 90% eff.)	4.1	2.9	-	7.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**73%**

4.6.3 CASE 3

4.6.3.1 Athens

The energy demands of the case study 3 in the weather conditions of Athens are presented in the following Tables.

Table 4.109. Total energy demand – Case 3- Athens

ENERGY DEMAND		[kWh/y]	[kWh/m^{2}y]	TOTAL
HEATING		8'944.5	6.7	
COOLING		55'936.5	41.9	
DHW		31'612.8	23.7	98.4
VMC_H -	heat recovery efficiency 0.5	4'292.4	3.2	
VMC_C-	heat recovery efficiency 0.5	30'570.8	22.9	

Table 4.110. Primary energy demand - Case 3 – Athens – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		[kWh/y]	[kWh/m^{2}y]	TOTAL
HEATING		10'408.8	7.8	
DHW		57'279.0	42.9	**78.2**
COOLING		23'504.3	17.6	
VMC_H -	heat recovery efficiency 0.5	13'254.4	9.9	

Table 4.111. Primary energy demand - Case 3 – Athens – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	1.7	6.2	-	7.9	
DHW	11.1	-	16.7	27.8	95.2
COOLING	-	45.0	-	45.0	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	2.1	8.8	-	10.8	
DHW	13.5	-	-	13.5	**55.2**
COOLING	-	22.4	-	22.4	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**29%**

Table 4.112. Primary energy demand - Case 3 – Athens – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	95.2
HEATING + tank losses	1.8	6.1	-	7.9	
DHW	11.1	-	16.7	27.8	
COOLING	-	45.0	-	45.0	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**48.3**
HEATING	2.2	5.3	-	7.5	
DHW	13.5	-	-	13.5	
COOLING	-	19.7	-	19.7	
VMC (heat recovery 90% eff.)	2.2	5.6	-	7.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**38%**

Table 4.113. Primary energy demand - Case 3 – Athens – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	98.3
HEATING + tank losses	8.5	-	-	8.5	
DHW	11.8	-	17.0	28.9	
COOLING	-	46.5	-	46.5	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**56.2**
HEATING	10.2	-	-	10.2	
DHW	14.3	-	-	14.3	
COOLING	-	23.1	-	23.1	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**28%**

Table 4.114. Primary energy demand - Case 3 – Athens – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	98.7
HEATING + tank losses	8.6	-	-	8.6	
DHW	12.0	-	16.6	28.6	
COOLING	-	46.9	-	46.9	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**56.8**
HEATING	10.4	-	-	10.4	
DHW	14.5	-	-	14.5	
COOLING	-	23.4	-	23.4	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**27%**

Table 4.115. Primary energy demand - Case 3 – Athens – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	8.5	-	-	8.5	97.9
DHW	11.8	-	16.6	28.4	
COOLING	-	46.5	-	46.5	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	3.0	-	-	3.0	**37.3**
DHW	4.2	-	-	4.2	
COOLING	-	23.1	-	23.1	
VMC (heat recovery 90% eff.)	0.6	6.3	-	7.0	
PRIMARY ENERGY REDUCTION respect to configuration 0					**52%**

4.6.3.2 Venice

The energy demands of the case study 3 in the weather conditions of Venice are presented in the following Tables.

Table 4.116. Total energy demand – Case 3- Venice

ENERGY DEMAND	**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING	40'050.0	30.0	107.5
COOLING	35'244.0	26.4	
DHW	38'047.5	28.5	
VMC_H - heat recovery efficiency 0.5	11'601.2	8.7	
VMC_C- heat recovery efficiency 0.5	18'556.5	13.9	

Table 4.117. Primary energy demand - Case 3 – Venice – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING	46'606.4	34.9	**111.2**
DHW	57'279.0	42.9	
COOLING	23'504.3	17.6	
VMC_H - heat recovery efficiency 0.5	21'030.0	15.8	

Table 4.118. Primary energy demand - Case 3 – Venice – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	6.4	26.2	-	32.5	105.9
DHW	15.6	-	17.2	32.8	
COOLING	-	28.1	-	28.1	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	7.7	19.3	-	27.0	**72**
DHW	18.9	-	-	18.9	
COOLING	-	15.9	-	15.9	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**35%**

Table 4.119. Primary energy demand - Case 3 – Venice – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	4.0	28.5	-	32.5	106.4
DHW	16.8	-	16.0	32.8	
COOLING	-	28.2	-	28.2	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	4.9	16.1	-	21.0	**62.3**
DHW	20.3	-	-	20.3	
COOLING	-	11.9	-	11.9	
VMC (heat recovery 90% eff.)	5.8	3.3	-	9.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**44%**

Table 4.120. Primary energy demand - Case 3 – Venice – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	35.2	-	-	35.2	111.4
DHW	16.8	-	17.6	34.3	
COOLING	-	29.3	-	29.3	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m²y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	42.6	-	-	42.6	**89.7**
DHW	20.3	-	-	20.3	
COOLING	-	16.6	-	16.6	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**19%**

Table 4.121. Primary energy demand - Case 3 – Venice – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	35.9	-	-	35.9	112.1
DHW	16.7	-	17.4	34.0	
COOLING	-	29.6	-	29.6	

VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	43.4	-	-	43.4	
DHW	20.1	-	-	20.1	**90.5**
COOLING	-	16.8	-	16.8	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**19%**

Table 4.122. Primary energy demand - Case 3 – Venice – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	35.6	-	-	35.6	
DHW	17.7	-	16.4	34.0	111.5
COOLING	-	29.3	-	29.3	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP**	**SOLAR**	**TOTAL**	
HEATING	12.6	-	-	28.9	
DHW	6.2	-	-	2.2	**41.5**
COOLING	-	10.6	-	10.6	
VMC (heat recovery 90% eff.)	1.7	4.5	-	6.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**63%**

4.6.3.3 Budapest

The energy demands of the case study 3 in the weather conditions of Budapest are presented in the following Tables.

Table 4.123. Total energy demand – Case 3- Budapest

ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		53'400.0	40.0	
COOLING		16'287.0	12.2	
DHW		41'118.0	30.8	108.4
VMC_H -	heat recovery efficiency 0.5	16'573.1	12.4	
VMC_C-	heat recovery efficiency 0.5	17'301.6	13.0	

Table 4.124. Primary energy demand - Case 3 – Budapest – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		62'141.9	46.5	
DHW		57'279.0	42.9	**128.7**
COOLING		23'504.3	17.6	
VMC_H -	heat recovery efficiency 0.5	28'852.3	21.6	

Table 4.125. Primary energy demand - Case 3 – Budapest – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	9.4	34.2	-	43.6	106.2
DHW	15.6	-	19.8	35.4	
COOLING	-	13.1	-	13.1	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	11.4	32.2	-	43.6	
DHW	18.8	-	-	18.8	**85.5**
COOLING	-	9.5	-	9.5	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**34%**

Table 4.126. Primary energy demand - Case 3 – Budapest – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	5.1	38.5	-	43.6	106.2
DHW	15.2	-	20.2	35.4	
COOLING	-	13.1	-	13.1	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	6.2	22.2	-	28.4	
DHW	18.4	-	-	18.4	**63.6**
COOLING	-	5.5	-	5.5	
VMC (heat recovery 90% eff.)	8.3	3.0	-	11.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**51%**

Table 4.127. Primary energy demand - Case 3 – Budapest – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	46.8	-	-	46.8	111.2
DHW	15.4	-	21.3	36.7	
COOLING	-	13.5	-	13.5	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	56.6	-	-	56.6	
DHW	18.6	-	-	18.6	**98.6**
COOLING	-	9.8	-	9.8	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**23%**

Table 4.128. Primary energy demand - Case 3 – Budapest – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	47.7	-	-	47.7	111.9
DHW	15.3	-	21.1	36.4	
COOLING	-	13.7	-	13.7	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	57.7	-	-	57.7	**99.6**
DHW	18.5	-	-	18.5	
COOLING	-	9.9	-	9.9	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**23%**

Table 4.129. Primary energy demand - Case 3 – Budapest – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	47.3	-	-	47.3	111.3
DHW	16.0	-	20.4	36.4	
COOLING	-	13.5	-	13.5	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	16.7	-	-	16.7	**39.8**
DHW	5.6	-	-	5.6	
COOLING	-	9.8	-	9.8	
VMC (heat recovery 90% eff.)	2.4	5.2	-	7.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**69%**

4.6.3.4 Helsinki

The energy demands of the case study 3 in the weather conditions of Helsinki are presented in the following Tables.

Table 4.130. Total energy demand – Case 3- Helsinki

ENERGY DEMAND		**[kWh/y]**	**[kWh/m²y]**	**TOTAL**
HEATING		74'760.0	56.0	125.1
COOLING		6'675.0	5.0	
DHW		47'953.2	35.9	
VMC_H -	heat recovery efficiency 0.5	28'190.8	21.1	
VMC_C-	heat recovery efficiency 0.5	9'463.8	7.1	

Table 4.131. Primary energy demand - Case 3 – Helsinki – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	[kWh/y]	[kWh/m²y]	TOTAL
HEATING	86'998.7	65.2	157.3
DHW	57'279.0	42.9	
COOLING	23'504.3	17.6	
VMC_H - heat recovery efficiency 0.5	42'154.4	31.6	

Table 4.132. Primary energy demand - Case 3– Helsinki – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	13.1	47.7	-	60.8	122.6
DHW	24.3	-	16.5	40.8	
COOLING	-	5.4	-	5.4	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	15.9	52.2	-	68.1	**118.5**
DHW	29.3	-	-	29.3	
COOLING	-	4.0	-	4.0	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**25%**

Table 4.133. Primary energy demand - Case 3 – Helsinki – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	7.1	53.7	-	60.8	122.6
DHW	28.1	-	12.7	40.8	
COOLING	-	5.4	-	5.4	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	8.6	39.2	-	47.7	**99.7**
DHW	34.0	-	-	34.0	
COOLING	-	2.2	-	2.2	
VMC (heat recovery 90% eff.)	14.2	1.6	-	15.8	
PRIMARY ENERGY REDUCTION respect to configuration 0					**37%**

Table 4.134. Primary energy demand - Case 3 – Helsinki – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	62.3	-	-	62.3	123.9
DHW	22.9	-	17.5	40.4	
COOLING	-	5.5	-	5.5	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	75.3	-	-	75.3	**124.2**
DHW	27.7	-	-	27.7	
COOLING	-	4.1	-	4.1	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**21%**

Table 4.135. Primary energy demand - Case 3 – Helsinki – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	62.9	-	-	62.9	124.6
DHW	22.9	-	17.5	40.4	
COOLING	-	5.6	-	5.6	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	76.1	-	-	132.4	**125.0**
DHW	27.7	-	-	16.5	
COOLING	-	6.5	-	6.5	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**20%**

Table 4.136. Primary energy demand - Case 3 – Helsinki – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	62.9	-	-	62.9	124.6
DHW	24.0	-	16.4	40.4	
COOLING	-	5.5	-	5.5	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	22.2	-	-	22.2	**41.9**
DHW	8.5	-	-	8.5	
COOLING	-	4.1	-	4.1	
VMC (heat recovery 90% eff.)	4.1	2.9	-	7.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**73%**

4.6.4 CASE 4

4.6.4.1 Athens

The energy demands of the case study 4 in the weather conditions of Athens are presented in the following Tables.

Table 4.137. Total energy demand – Case 4- Athens

ENERGY DEMAND		[kWh/y]	[kWh/m^{2}y]	TOTAL
HEATING		30'688.0	44.8	114.9
COOLING		9'590.0	14.0	
DHW		20'556.9	30.0	
VMC_H -	heat recovery efficiency 0.5	2'202.5	3.2	
VMC_C-	heat recovery efficiency 0.5	15'686.2	22.9	

Table 4.138. Primary energy demand - Case 4 – Athens – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		[kWh/y]	[kWh/m^{2}y]	TOTAL
HEATING		35'711.8	52.1	122.6
DHW		29'390.3	42.9	
COOLING		12'060.3	17.6	
VMC_H -	heat recovery efficiency 0.5	6'800.9	9.9	

Table 4.139. Primary energy demand - Case 4 – Athens – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING + tank losses	8.8	40.7	-	49.4	116.1
DHW	14.9	-	22.3	37.1	
COOLING	-	15.0	-	15.0	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	10.6	57.7	-	68.3	102.2
DHW	18.0	-	-	18.0	
COOLING	-	7.5	-	7.5	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					17%

Table 4.140. Primary energy demand - Case 4– Athens – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING + tank losses	13.1	36.4	-	49.4	116.1
DHW	14.8	-	22.4	37.1	
COOLING	-	15.0	-	15.0	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	79.6
HEATING	15.8	31.6	-	47.4	

DHW	17.9	-	-	17.9	
COOLING	-	6.6	-	6.6	
VMC (heat recovery 90% eff.)	2.2	5.6	-	7.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**35%**

Table 4.141. Primary energy demand - Case 4 – Athens – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	53.0	-	-	53.0	121.6
DHW	15.9	-	22.6	38.5	
COOLING	-	15.5	-	15.5	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	64.1	-	-	64.1	**99.6**
DHW	19.3	-	-	19.3	
COOLING	-	7.7	-	7.7	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**19%**

Table 4.142. Primary energy demand - Case 4 – Athens – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	54.1	-	-	54.1	122.5
DHW	15.9	-	22.3	38.2	
COOLING	-	15.7	-	15.7	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	65.4	-	-	65.4	**100.9**
DHW	19.2	-	-	19.2	
COOLING	-	7.8	-	7.8	
VMC (heat recovery 90% eff.)	2.2	6.3	-	8.5	
PRIMARY ENERGY REDUCTION respect to configuration 0					**18%**

Table 4.143. Primary energy demand - Case 4 – Athens – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	53.6	-	-	53.6	121.5
DHW	15.8	-	22.0	37.8	
COOLING	-	15.5	-	15.5	
VMC (heat recovery 90% eff.)	1.8	12.7		14.5	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**39.2**

HEATING	18.9	-	-	18.9	
DHW	5.6	-	-	5.6	
COOLING	-	7.7	-	7.7	
VMC (heat recovery 90% eff.)	0.6	6.3	-	7.0	
PRIMARY ENERGY REDUCTION respect to configuration 0					**68%**

4.6.4.2 Venice

The energy demands of the case study 4 in the weather conditions of Venice are presented in the following Tables.

Table 4.144. Total energy demand – Case 4- Venice

ENERGY DEMAND		**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING		61102.0	89.2	142.8
COOLING		2192.0	3.2	
DHW		19022.5	27.8	
VMC_H -	heat recovery efficiency 0.5	5'952.7	8.7	
VMC_C -	heat recovery efficiency 0.5	9'521.5	13.9	

Table 4.145. Primary energy demand - Case 4 – Venice – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND		**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING		71104.8	103.8	**180.1**
DHW		29390.3	42.9	
COOLING		12060.3	17.6	
VMC_H -	heat recovery efficiency 0.5	10790.7	15.8	

Table 4.146. Primary energy demand - Case 4 – Venice – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	27.7	67.8	-	95.5	143.4
DHW	15.2	-	16.8	32.0	
COOLING	-	3.4	-	3.4	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	33.5	50.0	-	83.4	**114**
DHW	18.4	-	-	18.4	
COOLING	-	1.9	-	1.9	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**37%**

Table 4.147. Primary energy demand - Case 4 – Venice – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	143.5
HEATING + tank losses	14.8	80.7	-	95.5	
DHW	15.7	-	16.4	32.0	
COOLING	-	3.4	-	3.4	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**92.9**
HEATING	17.9	45.5	-	63.4	
DHW	18.9	-	-	18.9	
COOLING	-	1.4	-	1.4	
VMC (heat recovery 90% eff.)	5.8	3.3	-	9.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**48%**

Table 4.148. Primary energy demand - Case 4 – Venice – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	153.0
HEATING + tank losses	103.4	-	-	103.4	
DHW	16.5	-	17.0	33.5	
COOLING	-	3.6	-	3.6	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**157.2**
HEATING	125.0	-	-	125.0	
DHW	19.9	-	-	19.9	
COOLING	-	2.0	-	2.0	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**13%**

Table 4.149. Primary energy demand - Case 4 – Venice – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	154.8
HEATING + tank losses	105.4	-	-	105.4	
DHW	16.0	-	17.2	33.2	
COOLING	-	3.6	-	3.6	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	
PRIMARY ENERGY [kWhp/m²y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	**159.1**
HEATING	127.5	-	-	127.5	
DHW	19.4	-	-	19.4	
COOLING	-	2.0	-	2.0	
VMC (heat recovery 90% eff.)	5.8	4.4	-	10.2	
PRIMARY ENERGY REDUCTION respect to configuration 0					**12%**

Table 4.150. Primary energy demand - Case 4 – Venice – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	104.5	-	-	35.6	153.8
DHW	16.4	-	16.4	34.0	
COOLING	-	29.3	-	29.3	
VMC (heat recovery 90% eff.)	4.8	7.7		12.6	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	36.9	-	-	36.9	**50.8**
DHW	5.8	-	-	5.8	
COOLING	-	2.0	-	2.0	
VMC (heat recovery 90% eff.)	1.7	4.4	-	6.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**72%**

4.6.4.3 Budapest

The energy demands of the case study 4 in the weather conditions of Budapest are presented in the following Tables.

Table 4.151. Total energy demand – Case 4 - Budapest

ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	82'474.0	120.4	173.8
COOLING	205.5	0.3	
DHW	19'022.5	27.8	
VMC_H - heat recovery efficiency 0.5	8'503.8	12.4	
VMC_C- heat recovery efficiency 0.5	8'877.6	13.0	

Table 152. Primary energy demand - Case 4 – Budapest – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	95'975.5	140.1	**222.2**
DHW	29'390.3	42.9	
COOLING	12'060.3	17.6	
VMC_H - heat recovery efficiency 0.5	14'804.4	21.6	

Table 4.153. Primary energy demand - Case 4 – Budapest – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	29.9	100.1	-	130.0	179.0
DHW	16.6	-	18.0	34.6	
COOLING	-	0.3	-	0.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	36.1	94.3	-	130.5	**164.3**
DHW	20.1	-	-	20.1	
COOLING	-	0.2	-	0.2	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**26%**

Table 4.154. Primary energy demand - Case 4 – Budapest – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	22.7	106.8	-	129.5	178.3
DHW	16.5	-	18.0	34.5	
COOLING	-	0.3	-	0.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	27.4	61.7	-	89.1	**120.4**
DHW	19.9	-	-	19.9	
COOLING	-	0.1	-	0.1	
VMC (heat recovery 90% eff.)	8.3	3.0	-	11.3	
PRIMARY ENERGY REDUCTION respect to configuration 0					**46%**

Table 4.155. Primary energy demand - Case 4 – Budapest – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	140.1	-	-	140.1	190.6
DHW	17.6	-	18.4	36.1	
COOLING	-	0.3	-	0.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	BOILER	HP/CHILLER	SOLAR	TOTAL	
HEATING	169.3	-	-	169.3	**204.5**
DHW	21.3	-	-	21.3	
COOLING	-	0.2	-	0.2	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**8%**

Table 4.156. Primary energy demand - Case 4 – Budapest – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	142.9	-	-	142.9	193.0
DHW	15.0	-	20.7	35.7	

COOLING	-	0.3	-	0.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	172.7	-	-	172.7	**204.6**
DHW	18.1	-	-	18.1	
COOLING	-	0.2	-	0.2	
VMC (heat recovery 90% eff.)	8.3	5.2	-	13.6	
PRIMARY ENERGY REDUCTION respect to configuration 0					**8%**

Table 4.157. Primary energy demand - Case 4 – Budapest – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	141.6	-	-	141.6	191.7
DHW	17.5	-	18.2	35.7	
COOLING	-	0.3	-	0.3	
VMC (heat recovery 90% eff.)	6.9	7.2		14.1	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	50.0	-	-	50.0	**64.0**
DHW	6.2	-	-	6.2	
COOLING	-	0.2	-	0.2	
VMC (heat recovery 90% eff.)	2.4	5.2	-	7.7	
PRIMARY ENERGY REDUCTION respect to configuration 0					**71%**

4.6.4.4 Helsinki

The energy demands of the case study 4 in the weather conditions of Helsinki are presented in the following Tables.

Table 4.158. Total energy demand – Case 4- Helsinki

ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	115'491.0	168.6	231.8
COOLING	-	-	
DHW	23'975.0	35.0	
VMC_H - heat recovery efficiency 0.5	14'464.9	21.1	
VMC_C- heat recovery efficiency 0.5	4'856.0	7.1	

Table 159. Primary energy demand - Case 4 – Helsinki – Configuration 0

Configuration 0 – PRIMARY ENERGY DEMAND	**[kWh/y]**	**[kWh/m^{2}y]**	**TOTAL**
HEATING	134'397.6	196.2	**288.3**
DHW	29'390.3	42.9	
COOLING	12'060.3	17.6	
VMC_H - heat recovery efficiency 0.5	21'629.8	31.6	

Table 4.160. Primary energy demand - Case 4 – Helsinki – Configuration 1

CONFIGURATION 1					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	44.7	134.2	-	178.9	236.2
DHW	24.7	-	16.9	41.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	54.1	146.9	-	201.0	
DHW	29.9	-	-	29.9	**248.0**
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**14%**

Table 4.161. Primary energy demand - Case 4 – Helsinki – Configuration 2

CONFIGURATION 2					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	26.8	152.0	-	178.9	263.2
DHW	28.7	-	12.9	41.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	32.4	110.9	-	143.3	
DHW	34.7	-	-	34.7	**193.8**
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	14.2	1.6	-	15.8	
PRIMARY ENERGY REDUCTION respect to configuration 0					**33%**

Table 4.162. Primary energy demand - Case 4 – Helsinki – Configuration 3

CONFIGURATION 3					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	184.9	-	-	184.9	242.2
DHW	23.6	-	18.0	41.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	
PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	223.5	-	-	223.5	
DHW	28.6	-	-	28.6	**269.2**
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**7%**

Table 4.163. Primary energy demand - Case 4 – Helsinki – Configuration 4

CONFIGURATION 4					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	186.9	-	-	186.9	244.2
DHW	23.6	-	18.0	41.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	225.9	-	-	225.9	**271.6**
DHW	28.6	-	-	28.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	14.2	2.9	-	17.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**6%**

Table 4.164. Primary energy demand - Case 4 – Helsinki – Configuration 5

CONFIGURATION 5					
SUPPLIED ENERGY [kWh/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING + tank losses	197.7	-	-	197.7	256.9
DHW	25.9	-	17.7	43.6	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	11.7	3.9		15.7	

PRIMARY ENERGY [kWhp/m^{2}y]	**BOILER**	**HP/CHILLER**	**SOLAR**	**TOTAL**	
HEATING	69.8	-	-	69.8	**86.0**
DHW	9.2	-	-	9.2	
COOLING	-	-	-	-	
VMC (heat recovery 90% eff.)	4.1	2.9	-	7.1	
PRIMARY ENERGY REDUCTION respect to configuration 0					**70%**

4.7 Conclusions

The analysis carried out proves that it is possible to drastically reduce the primary energy demand of a building by the means of simple actions carried on the envelope and on the HVAC system.
The analysis highlight how the first step in the retrofit on a residential building should always be an opportune redevelopment of the envelope, with an improvement of the thermal insulation of the opaque structures and the substitution of windows with ones with better thermal performance.
The replacement of windows allows to reduce the thermal energy demand to a values variable between the 60% and the 86% of the earlier state; achieving an energy saving variable between the 40% and the 14% respectively. This value depends from several parameters, such as the climate and the kind of building, but it represents a consistent rate of energy reduction, and it is important to notice that it is feasible with a not invasive action.

The equipment of the envelope with increasing thickness of insulation decreases consistently the energy demand. The retrofitted building presents an energy demand that is between the 32% and the 58% of the earlier value (action 3). And the energy demand reduction rate increase even more considering the actions 4,5, and 6 in which the envelope insulation is combined with the replacement of windows, in the most performing solution the energy demands decreases to the 20% to 40% of the initial value.
The redevelopment of the HVAC systems has shown how much primary energy could be saved acting on the technical devices. Results show the great opportunity represented by integrated energy systems, where different heat and cold generators are integrated to satisfy the users energy demand, allowing the using of renewable energy resources where they are advantageous. The primary energy reduction rate obtained in the analysis are greatly variable, due to the fact that many parameters concur to the final results. Resuming very generally what the analysis has shown it is possible t conclude that integrated system could always guarantee a primary energy saving. This value is greater for solutions equipped with water condensed heat pumps and condensing boilers (configuration 2), respect to cases with air condensed heat pumps (configuration 1). The replacement of standard boiler with condensing ones gives almost comparable results in the use of fan coil or radiators, and the gain is primarily due to the increased boiler efficiency(configurations 3 and 4). The greatest reduction in the primary energy demand has been achieved by the use of a pellet fired boiler, because of the low conversion factor of energy obtained by biomass combustion into primary energy (configuration 5).
Solar thermal collectors have been considered in every case analyzed. Their contribution is restricted to the DHW generation because of a technical choice. They supply a considerable amount of energy, usually greater than the 50% of the DHW energy demand as it is demanded by Italian standard. Of course this value can be changed easily increasing or decreasing the area of the solar field. In this analysis a compromise between costs and solar energy supply has been chosen.

4.8 References

[1] Official Journal of the European Communities, Directive 2002/91/CE of the European Parliament and of the Council of 16 December 2002 on the energy performances of buildings, l1/65,2003
[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performances of buildings (recast)
[3] R. Hartless, Application of Energy Performance Regulations to Existing Buildings, Final Report of the task B4, ENPER TEBUC, SAVE 4.1031/C/00-018/2000, Building research establishment, Wathford, UK, 2003.
[4] F. Stazi et Al., Retrofitting using a dynamic envelope t ensure thermal comfort, energy savings and low environmental impact in Mediterranean climates, Energy and Buildings, 54 (2012) 350-362.
[5] M. Morelli et Al., Energy retrofitting of a typical old Danish multy-family building to a "nearly-zero" energy building on experiences from a test apartment, Energy and buildings, 54 (2012) 395-406.
[6] Proceedings of the 7th International Conference on Energy Efficiency in Commercial Buildings IEECB'12, P. Bertoldi, G. Trenev, Joint Research Centre, 2013, pag 48
[7] S. Nabinger, A. Persily, Impacts of airtightening retrofits on ventilation rates and energy consumption in a manufactured home, Energy and Buldings, 43 (2011) 3059-3067
[8] UNI TS 11300- part 2
[9] C. Verhoest, Y.Ryckmans, Industrial Wood pellet Report, 22 March 2012, pag 28.

CONCLUSIONS

The present thesis aimed to analyze integrated solutions to reduce the energy demand and to promote the development of renewable resources in the residential sector.
A brief overlook on the stats of the European Building stock and on the current energy situation according to the demand for heating, cooling and DHW (Domestic Hot Water) generation has been provided. In European Union (EU) the building sector is responsible of about the 40% of the total final energy consumption and of the 36% of the Europe global CO_2 emissions.
These data justify the strong motivation of the European Commission towards the modernization of the existing building structures and toward the development of more efficient HVAC systems, capable of integrating different energy sources to meet through renewable energy at least part of the thermal need.
Integrated Multienergy Systems (IMES) were evaluated in combination with single dwellings and multifamily buildings, to asset their applicability domain. By means of dynamic smulatios, carried out with the transient code TRNSYS, models have been created according both to the building envelopes and to the thermal system, in order to evaluate the energy saving possiblities related to their redevelopment. The analysis carried out proves that it is possible to highly reduce the primary energy demand of a building by the means of simple actions carried on the envelope and on the HVAC system. The analysis, in particular, highlights how the first step in the retrofit on a residential building should always be an opportune redevelopment of the envelope, through the improvement of the thermal insulation of the external structures and the substitution of windows with ones with better thermal performance.
The replacement of windows, alone, allows an energy saving variable between the 40% and the 14% of the ante-opera state. The actual value depends from several parameters, such as the climate and the kind of building, but it represents a consistent rate of energy reduction, and it is important to notice that it is feasible with a not invasive action. The insulation of the envelope could achieve a consistently decrease in the energy demand, allowing to reach a post retrofit value variable between the 32% and the 58% of the earlier value. The combination of the two actions, insulation of the envelope and windows replacement, has proved to be the most performing solution, allowing a decrease of the energy demands up to the 20% to 40% of the initial value.
The redevelopment of the HVAC systems has shown how much primary energy could be saved acting on the technical devices. Results show the great opportunity represented by IMES, where different heat and cold generators are integrated to satisfy the users energy demand, allowing the using of renewable energy resources where they are advantageous. The primary energy reduction rate obtained in the analysis are greatly variable, due to the fact that many parameters concur to the final results. The performance of several IMES have been compared to determine the best configuration in order to achieve the minimum primary energy demand to satisfy the thermal energy required by the users. Some solutions have been evaluated in order to improve the contribuition of the renewable energies, like as solar energy and the renewable share of the energy provided by the heat pumps. The supply of the solar plant, as demanded by Italian regulation, for every analyzed case met more than 50% of the thermal energy requirement for the production of sanitary hot water and at least the 20% of the total thermal energy demand. As for the solar system it must be noted that, as shown in the second chapter, the poor energy contribuition provided to the heating circuit induced to eliminate that section of the

plant, obtaining some economical benefits, the semplifiction of the system and the increase of the energy provided to the DHW service.
The component whose contribution is more variable is the heat pump. It can provide a consistent energy contribution in favorable conditions, but the system must be designed very carefully. The size of the device and the thermal capacity of the storage connected to the heat pump are the most important parameters to be fixed in order to achieve a good performance. Furthermore the operation of the heat pump is highly affected by the weather conditios, hence, according to the climatic conditions, the choice of the refrigerant fluid is foundamental. Athought the second chapter of the thesis shows how the heat pump can cover the 20.8 % of the total energy required, even if the design condition were not ideal, while the boiler provides the remaining 53.4 % of the heat load integrated by the soalr thermal collectors. The results prove, besides, how the IMES solution is not particularly suitable for installation in facilities that provide radiators as emission devices, especially in the applications within poorly insulated building, whose high energy demand requires high flow rate for the heating circuit, incompatible with the stratification phenomena inside the tank and with the synergy between the boiler and the heat pump.
Resuming very generally what the various analyses have shown it is possible to conclude that integrated systems (IMES) can always guarantee a primary energy saving. The greatest reduction in the primary energy demand has been achieved by the use of a pellet fired boiler, because of the low conversion factor of energy obtained by biomass combustion into primary energy. The replacement of standard boiler with condensing ones gives almost comparable results in the use of fan coil or radiators, and the gain is primarily due to the increased boiler efficiency This value is greater for solutions equipped with water to water heat pumps and condensing boilers, respect to cases with air to water heat pumps.. In mild and warm climates nevertheless very often is needed to cool the building, hence heat pumps seem the most favorable solutions in the retrofit.

ANNEX

A

EXPERIMENTAL MEASUREMENTS FOR THE CALIBRATION OF THERMAL STORAGE MODEL

Abstract
The calibration of the thermal storages of the HVAC system analyzed in the chapter 3 was carried out through the performing of laboratory test at the laboratories of one of the companies involved in the projects. The testing purpose was making a comparison between the real and the simulated behavior of thermal storages, in order to adjust the model created by the numerical code TRNSYS, to reduce errors and approximations of the simulations. In addition, laboratory tests have allowed to collect information about how the heat exchange takes place according to the heat convention and to the flow of the fluids inside the tanks. Through the test, also, the technical and thermal characteristics of the coil heat exchangers have been investigate, considering that they were not known since are these storage tanks are not produced by the companies but purchased from third parties.

A.1. The test facilities

The test facilities have been provided by the research laboratory and development of one of the companies involved in the study. The laboratory consists of two loading/unloading ramps (one hot and one for cold water), a boiler, two storage tanks and the necessary measuring instruments. The ramps are basically storage tanks which have the purpose of receiving a quantity of water at the desired temperature or to deliver the water processed during the test. The ramps can interact with each other so as to make possible the mixing of the water contained in the tanks thus obtaining the required temperature. Each ramp consists of two tanks with capacity of 1860 l and is managed by stationary pumps which are connected to volumetric flow meters.
The boiler used was a condensing coiler ,with a power output equal to 30 kW, which allows to heat the water needed for the tests. The technical features of the boiler are given in Table 165.

Table 165. Technical features of the boiler used in the laboratory tests

Item	Value
Power rate (80-60°C)	28,9 kW
Power rate (50-30°C)	31,6 KW
Efficiency min/max (80-60°C)	95/98
Efficiency min/max (50-30°C)	107/107

In the test facility was not possible install the same tanks being analyzed in the chapter 3, as they were too large to be handled in the laboratory due to the flow rate they require. Were, therefore, taken into consideration tanks smaller and more manageable, chosen so as to ensure a geometric similarity with those of the project. The geometric characteristics of the comparison are height and diameter of the storage tanks. The ratio D/L of the heating storage, PUFFER 1S 2000, equal to 0.47, was compared with the corresponding ratio of the other available devices. The storage that better met with the required geometry was the PUFFER 1S 800, which presents a D/L ratio equal to 0.49. The same procedure was performed to identify the DHW test tank. The DHW thermal storage 2S 2000 implement in the case study had a D/L ratio equal to 0.43 , the tank chosen for the test is 2S 750 which ratio value is equal to 0.42.
Although the tanks used in the tests were different from those of the case study, due to their geometry similarity, they are expected to present very similar behavior . Calibration results obtained on these tanks could, therefore, be transferred to larger ones without making significant errors .
Table 166 and Table 167 provide the technical characteristics of the tanks used in the tests.

Table 166. Geometrical features of the tank PUFFER 1S 800

Item	Value
Junction / Probe / A duct probe	260 mm
Junction / Probe / duct probe B	630 mm
Junction / Probe / C duct probe	1030 mm
Junction / probe / probe duct D	1380 mm
Back exchanger E	260 mm
Flow heat exchanger F	930 mm
Height without insulation h	1620 mm
Height with insulation H	1700 mm
Diameter with insulation OD	990 mm
Diameter without insulation ø int	790 mm
Ø thread	1 ½ "
Junction probe ø thread	½ "
Junction exchanger ø thread	1 "

Table 167. Technical and thermal features of the tank PUFFER 1S 800

Item	Value
Tank volume	790 l
Maximum operating pressure	3 bar
Maximum operating temperature	95°C
Maximum operating pressure coils	10 bar
Maximum operating temperature coils	110°C
Exchange surface coil	2,4 m²
Capacity of the coil	15,2 l
Power consumption lower coil	65 kW
Required flow – top coil	2,8 m³/h
Coil pressure drop	33 mbar
Hot water generation Δt 35°C (80°/60°C - 10°/45°C)	795 l/h
Hot water generation Δt 35°C (80°/60°C - 10°/45°c)	31 kW
Thickness of insulation	100 mm
Insulation type	Soft polyurethane
Empty weight	140 kg

Table 168. Geometrical features of the tank 2S 750

Item	Value
A Flange	400 mm
B Electrical resistance 1 ½"	268 mm
C Thermometer ½ "	1460 mm
F Cold 1 ¼ "	220 mm
G Return the solar circuit 1 1/4 "	385 mm
Solar circuit probe ½ "	685 mm
M Solar circuit flow 1 ¼ "	835 mm
N Heating return 1 ¼ "	990 mm
P Heating probe ½ "	1340 mm
Q Recirculation 1 "	1235 mm
R Heating flow 1 ¼ "	1440 mm
S Hot water 1 ¼ "	1590 mm
H Total height	1870 mm
ø out Outer diameter (with insulation)	940 mm
ø int Inner Diameter (without insulation)	790 mm

Table 169. Technical and thermal features of the tank 2S 750

Item	Value
Tank Volume	750 l
Maximum Operating Pressure	10 bar
Maximum operating temperature	95°C
Maximum operating pressure coils	10 bar
Maximum operating temperature coils	110°C
Exchange surface serpentine top	2,5 m²
Exchange surface coil lower	2,5 m²
Capacity of the coil at the top	13,3 l
Capacity of the bottom coil	13,3 l
Power consumption serpentine top	48 kW
Power consumption lower coils	48 kW
Required flow serpentine top	2,17 m³/h
Required flow serpentine top	2,17 m³/h
Pressure drop serpentine top	30 mbar
Pressure drop lower coils	30 mbar
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) upper coil	1000 l/h
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) upper coil	1600 l/h
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) lower coil	59 kW
Hot water generation ΔT 35°C (80°/60°C - 10°/45°C) lower coil	59 kW
Thickness of insulation	70 mm
Insulation type	Rigid polyurethane
Empty weight	238 kg

The hydraulic circuit is provided with an open expansion vessel so as to compensate the thermal expansion of the water inside the storage that may occur for temperature over 60 °C.
The measuring instruments used are temperature sensors, flow and pressure meters. The temperature probes are used thermocouple PT100 class A+ with a transmitter (TMT181) with an uncertainty interval equal to ± 0.25 °C. They were placed inside the tank through the predisposed junctions. It has to be noticed that the positions of the probe differs not only acceding to the heath of the junctions to the tanks, but also for the depth to which they are placed. In fact, the presence of the coil heat exchanger, makes impossible to place the temperature probe at the same depth. In the PUFFER 1S 800 the sensors, placed them in the lower connections (3-4), have been positioned a few inches from the external wall of the tank, while the probes installed in the higher junctions have been placed few centimeters deeper into the tank volume. The same could be said according to the second tested storage the DHW 2S 750.
The flow meters installed were magnetic devices for the measure of the volumetric flow rate, expressed in m³/h with a range of uncertainty of ± 0.00065 m³/h. The pressure gauges are mainly used for security purposes, to asset to not exceed the maximum working pressure.
Inside the lab a data acquisition system was available which allowed to record the measuring instruments output values at customizable periods.

A.2. The test on the thermal storage PUFFER 1S 800

The test carried out for the heating storage tanks are 6, to evaluate every possible performance of the storage according to heat exchanged within the several circuit connected to the device, like as the boiler, the solar system and the heating circuit. In addition, some comparisons were performed to achieve the calibration of the TRNSYS model of the storage respect to the real component. To calibrate the simulation model the laboratory facilities and the performed test have been reproduced trough the code TRNSYS. The test, also, allowed to determine the physical property of the coiled heat exchanger, according to sizes, thickness, tube material, pitch and diameter of the coils. These items are, furthermore, required by the software to perform a correct simulation and to estimate the heat exchange through the coil and fluid outlet temperatures. The first two tests have were performed in order to calibrate the system, while the subsequent tests are intended to investigate the behavior of the storage during its operation .

A.2.1 Test 1: Heating through the solar coil heat exchanger

This test has been carried out to assess the performance of the coil heat exchanger of the solar system during the heating of the tank inner volume. The initial temperature conditions of the tank are shown in Table 170 As can be seen in Figure 27, the solar system is replicate by the means of the test facility boiler, which is called to provide hot water for the test. The hot flow has been mixed with a cold flow rate to adjust the temperature of the fictive solar fluid to the desired value. Four temperature probes have been provided to the tank in order to record the temperature variation of the inner water volume. Initial conditions for the temperature recorded by the probe, and boundary test conditions are presented in Table 170.

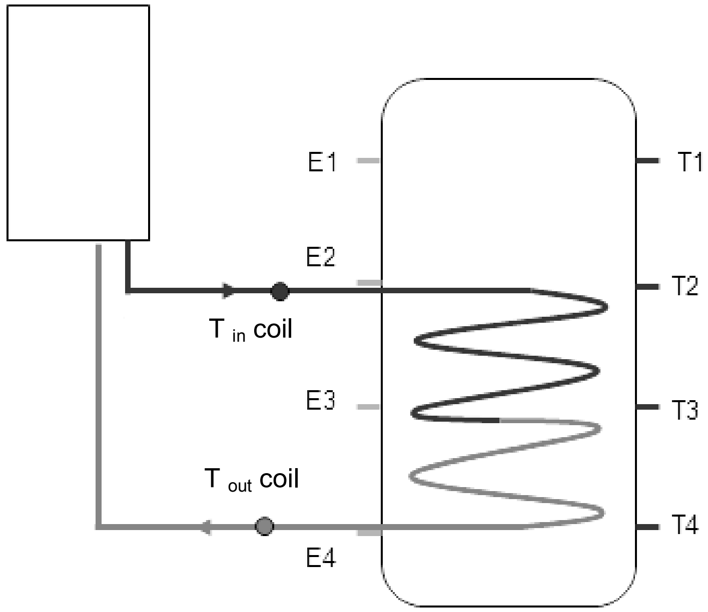


Figure 27. Facility for the solar coil load test of the PUFFER 1S 800

Table 170. Initial and boundary conditions TEST 1

Item	Value
T1 initial value	21,8 °C
T2 initial value	18,4 °C
T3 initial value	17,8 °C
T4 initial value	16,8 °C
Average ambient temperature	22,2 °C
Boiler temperature set point	80 °C
Average flow boiler	750 l/h
duration of test	3 h
Range data acquisition	5 sec

The data recorded during the test have been analyzed to evaluate the heating power rate according to the coil heat exchanger. The mathematical relation for the heat transfer by the means of a fluid flow through an exchanger is expressed by the Equation (1)

$$q = \rho \, m_v c_p \, \Delta T \quad (1)$$

where the fluid density, the mass flow rate, the fluid specific heat capacity and the difference of temperature between the inlet and the outlet are involved.
Since the recorded data are experimental measures, the density and the specific heat of the fluid magnitudes depend on the temperature. To perform a precise calculation of the mass flow rate and the power exchanged it is necessary to know the value of these properties at any water temperature. The property of water have been calculated by an interpolation of literature data.

According to the temperature of the fluid at the inlet of the coil, through the Lagrange polynomial interpolation, the values density, compression factor, thermal conductivity, specific heat at constant pressure, dynamic and kinematic viscosity and the Prandtl number have been evaluated.
The data obtained during the laboratory test are subject to uncertainty of measurement and they must be corrected to avoid the error propagation. In the calculation of the temperature difference the error propagation depends from the sum of the uncertainties of the two temperature values involved. The thermometers present an absolute error of ± 0.25 °C, so the uncertainty in this case assumes the value of ± 0.50 °C . The situation is more complex in the case of the calculation of the thermal power , which involved several variables with different errors. Moreover the specific heat and density of the fluid are variables dependent from temperature, which is a recorded data, and so affected by uncertainty. In the case studied specific heat and density have, respectively, absolute error equal to ± 0.02 kg/m and ± 0.0005 kJ/kg K. Finally the absolute error of the flow rate can be evaluated in 0.65 l/h and, by means relationship expressed in the Equation (2), it is possible to obtain the value of the thermal power and its uncertainty:

$$q = (\rho \pm 0{,}02) \cdot (m_v \pm 0{,}65) \cdot (c_p \pm 0{,}0005) \cdot (\Delta T \pm 0{,}5) =$$
$$= \rho m_v c_p \Delta T \ \pm (0{,}65\ \rho c_p \Delta T + 0{,}002\ m_v c_p \Delta T + 0{,}05\ \rho m_v \Delta T + 0{,}5\ \rho m_v c_p) \qquad (2)$$

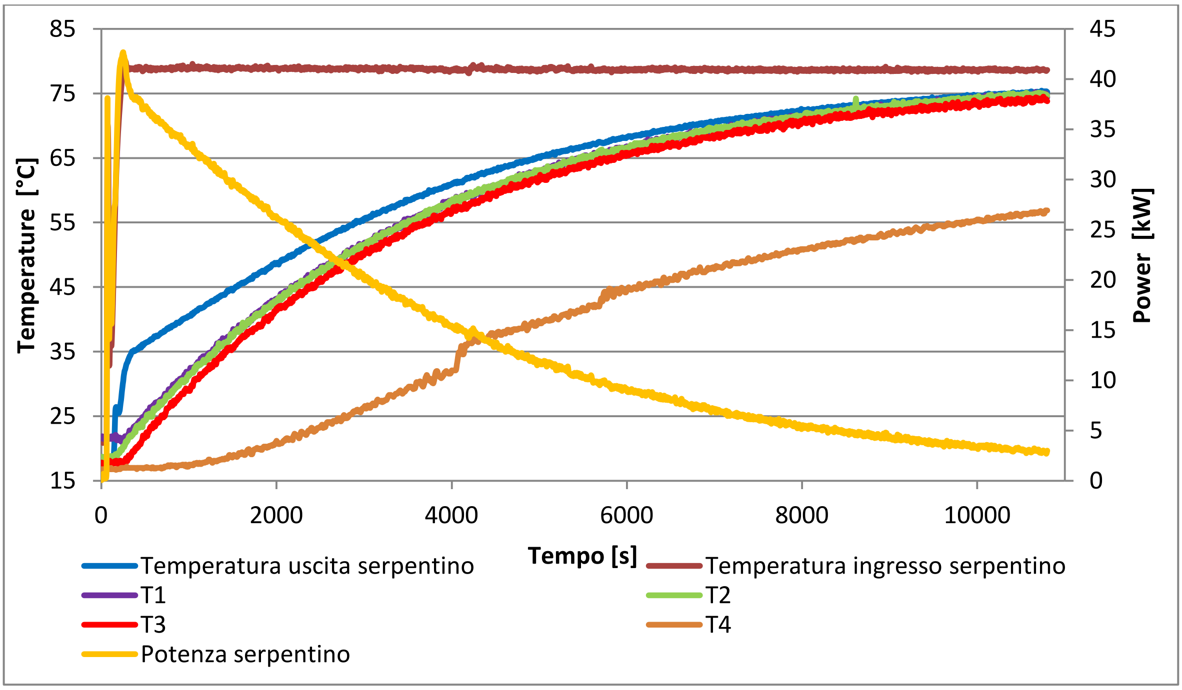


Figure 28. Results TEST 1

Table 171. Initial values of the coil heat exchanger of the solar circuit

Item	Value
Outside Diameter	0,0254 m
Inner Diameter	0,0194 m
Thermal conductivity	200 kJ/h m K
Tube length	30 m
Coil Diameter	0,7 m
Coil Pitch	0,04 m

The test 1 was very important to solve some doubts about the implementation of the characteristics of the coil in the TRNSYS model. Also, it was essential to observe the operation of the modeled heat exchanger at knowing the initial conditions in order to calibrate the simulation respect to the measure recorded on the real component.

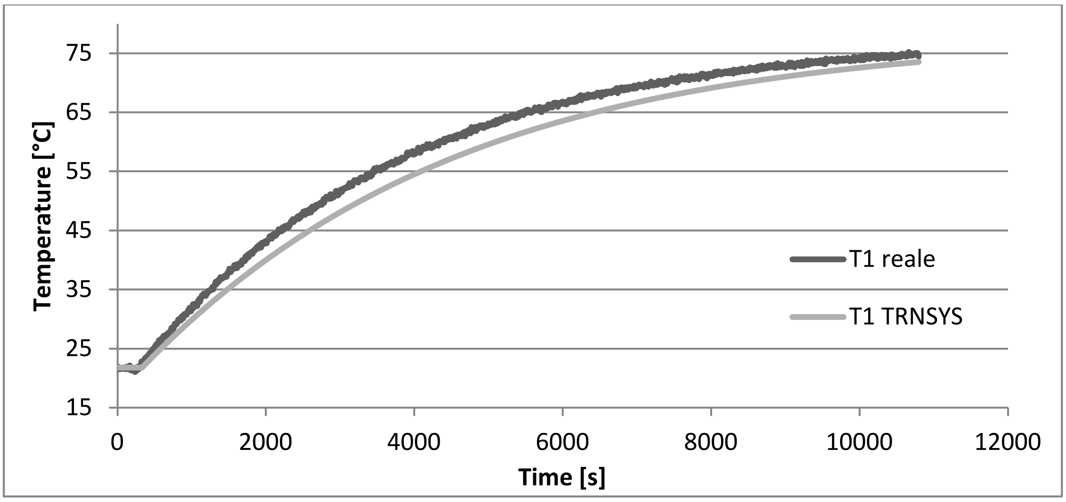


Figure 29. T1 temperatures comparison Test 1

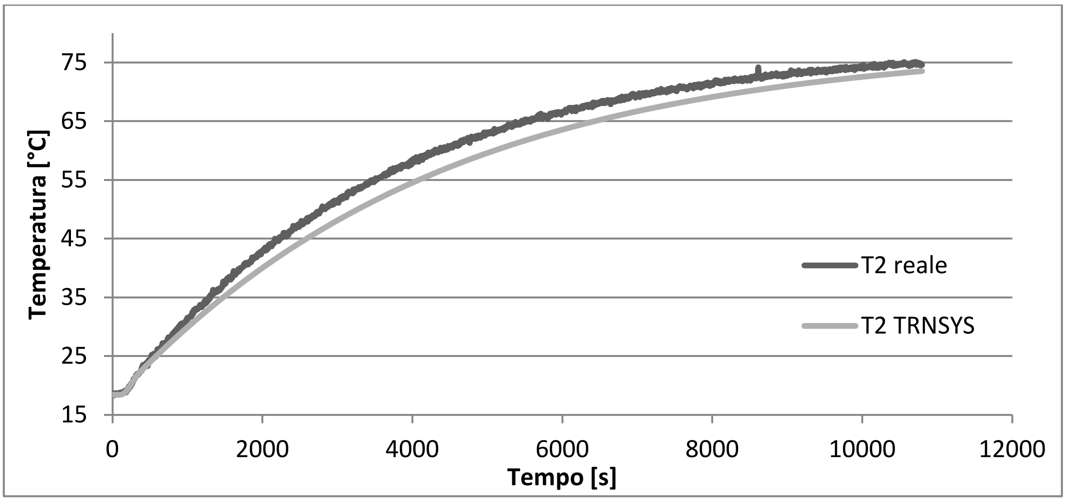


Figure 30. T2 temperatures comparison Test 1

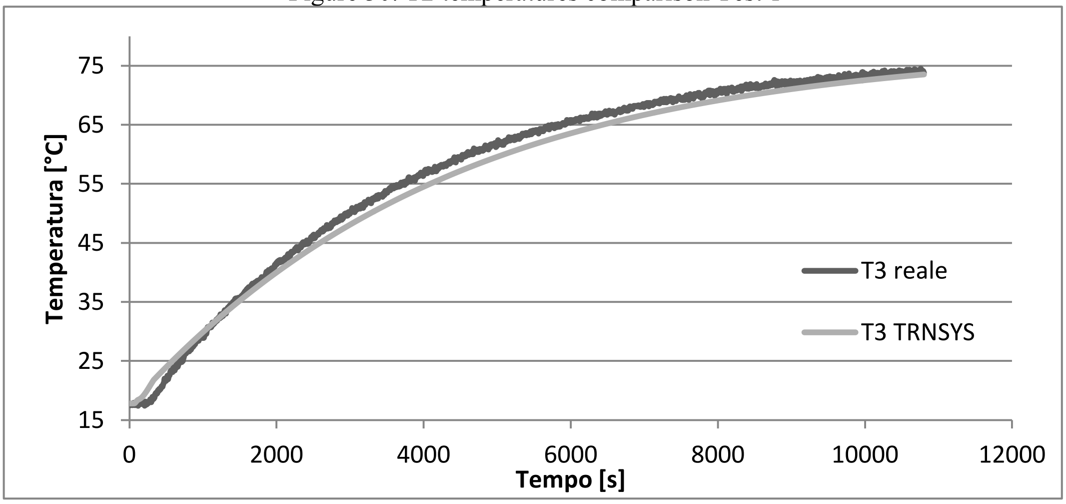


Figure 31. T3 temperatures comparison Test 1

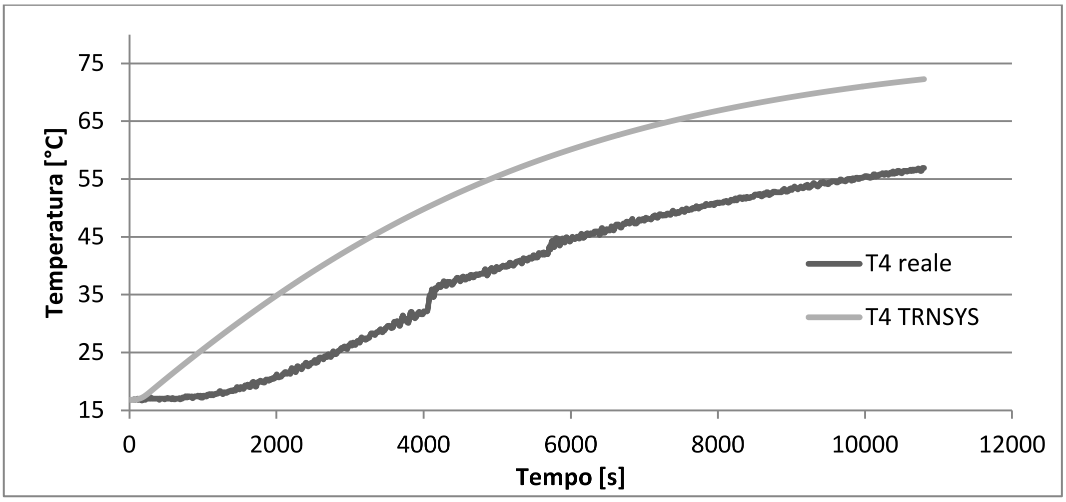


Figure 32. T4 temperatures comparison Test 1

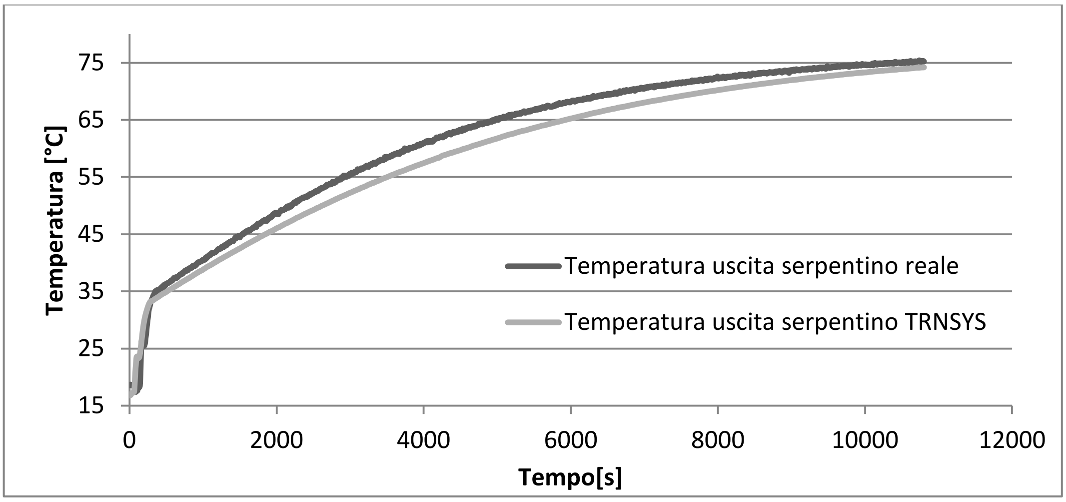


Figure 33. Coil outlet temperatures comparison Test 1

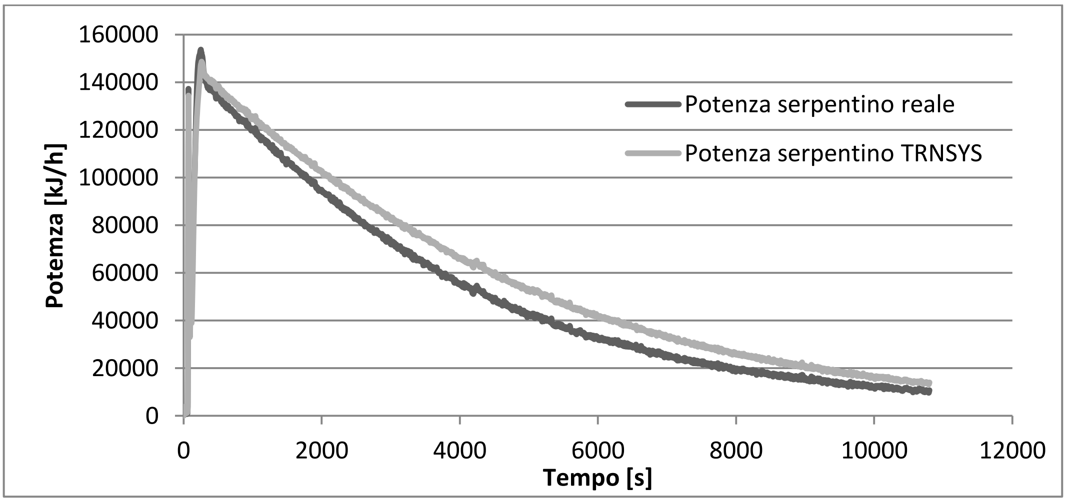


Figure 34. Coil power comparison Test 1

From the graphs it can be seen that the temperature of the water contained in the tank in correspondence of the nodes 1 , 2 and 3 , in the real case are slightly higher than in the virtual case. The most significant difference occurs at the node 4 , the lower one, in fact an average difference between of 14.4 ° C and a maximum difference of 18.4 ° C has been obtained. It has been esteem that this difference was not caused by an incorrect operation of the simulated model, but by the position of the temperature probe, which being positioned at a lower height of the coil of the accumulation registers a lower value than the one estimated by the software. Within the software you can set only the number of nodes with which to divide the tank and then they have a fixed equal height. The bottom node considered by the simulator as a single volume element thus contains a portion of the coil and it is clear that the temperature will be higher because of the effect of the heat exchanger.
Regarding the comparison between the exchanged power and temperature output from the coil is noted that with the initial implemented characteristics, the coil tends to achieve a more effective heat exchange than in the real case, as it is shown in Figure 34. Also the measured outlet temperature from the coil is higher respect to the simulated value (Figure 33), in fact the higher temperature difference, being the same the inlet temperature, necessary take to an higher heat exchanged.
To make a better comparison of this phenomenon, the overall heat transfer coefficient (K) of the coil has been calculated.

$$q = K\ S\ \Delta T \tag{3}$$

Being note the power by the equation (4)

$$q = m\ c_p\ \Delta T \tag{4}$$

it is possible to calculate the value of K, considering that the outer surface of thermal exchange and the average temperature difference between the water that circulates inside the tube and the external water contained accumulation are known quantities.

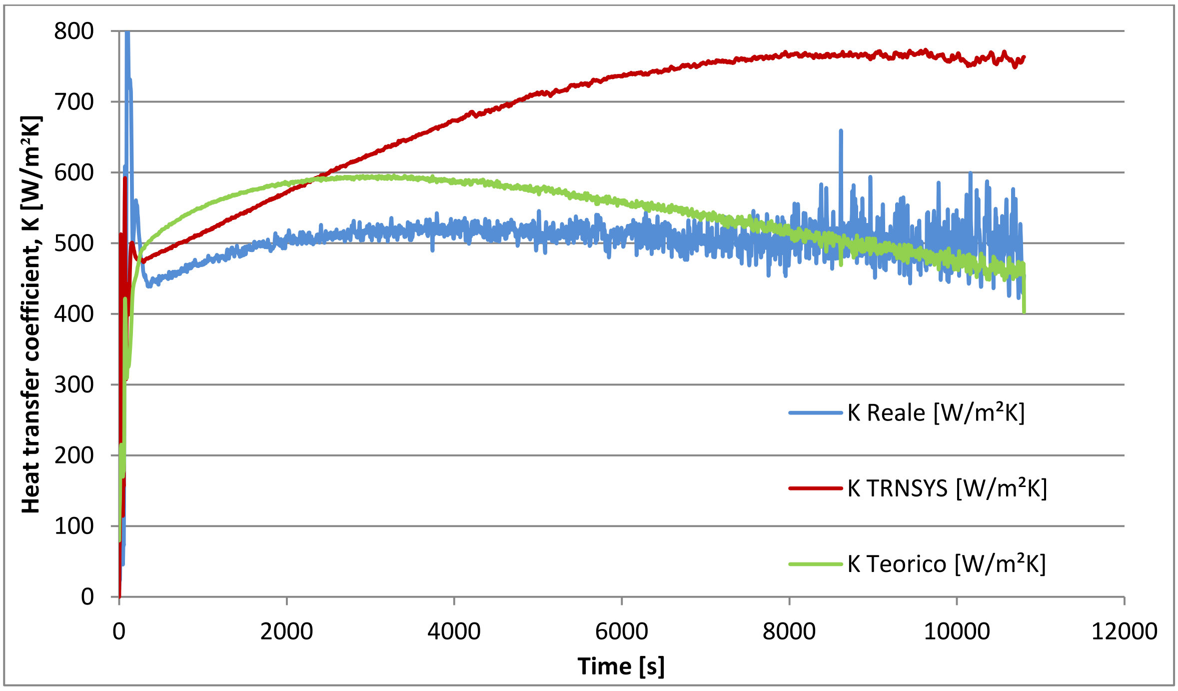


Figure 35. Solar heat exchange coefficient

As shown in Figure 35 the evaluation of the theoretical heat exchange coefficient has been done, b y the means of the Equation (5):

$$K = \frac{1}{\frac{1}{\alpha_i}+\frac{1}{h_{tubo}}+\frac{1}{\alpha_e}} \tag{5}$$

The equation requires not only the conductive heat transfer coefficient of the coil but also the convention Exchange factors of the internal and external coil surfaces: α_i and α_e.
The convective internal coefficient can be evacuate according to the Nusselt number on the basis of the mathematical Equation (6):

$$\alpha_i = \frac{Nu\,\lambda}{d} \tag{6}$$

To use the proper correlation for the evaluation of the Nusselt number, it is necessary to know if the fluid flow inside the coil is laminar or turbulent. The mode of out flowing of the flow rate depends on the Reynold number, evaluable according to the equation (7) :

$$Re = \frac{\rho\, d\, v}{\mu} \tag{7}$$

where v is the average velocity of the flow [m/s], evaluated according to the volumetric flow rate and to the flow section on the basis of the equation $v = \frac{Q}{A\,3600}$, and d is the internal diameter of the tube. The density (ρ) and the dynamic viscosity (μ) of the fluid are evaluated according to the average temperature between the inlet and the outlet value of the coil , $t = \frac{t_i - t_e}{2}$.
The calculated Reynolds number is higher than 33500 so the turbulent flow mode is confirmed. To calculate the Nussel number the Dittus Boelter Equation (8) has been used:

$$Nu = 0{,}024\, Re^{0{,}8} Pr^{0{,}4} \tag{8}$$

The average internal convective coefficient is equal to 4966 W/m²K.
Regarding the external average convective coefficient, natural convective conditions along an horizontal tube have been assumed. In fact the coil is placed inside the tank with a vertical longitudinal axis, so that the coiled tube can be considered almost horizontal. According to natural convention the Nusselt number has been evaluated on the basis of the Equation (9):

$$Nu = 0{,}47\, Ra^{1/4} \tag{9}$$

where Ra represents the Raylight number, which is equal to the multiplication of the Prandtl number and the Grashof number. The Grashof number could be evaluated according to the Equation (10):

$$Gr = \frac{g\,\rho^2 \beta d^3 (T_{pe} - T_\infty)}{\mu^2} \tag{10}$$

where, g gravitational acceleration, ρ e μ e β respectively represent density, viscosity and the volumetric coefficient of thermal expansion of water, d the external diameter of the tube, T_∞ the average temperature within the storage and T_{pe} the temperature of the outer wall of the tube. This temperature can be calculated using the following procedure. (Please note that the valor of the properties of water are related to the average temperature between T_2 and T_3 and T_∞).
Note the average temperature of the water that circulates inside the tube and the convective coefficient calculated previously the temperature of the inner wall can be calculated with the Equation (11):

$$q = \alpha_i A \left(T_i - T_{pi}\right) \tag{11}$$

once T_{pi} has been evaluated, the temperature of the outer wall of the tube can be calculated according to the equation of heat conduction through the tube , Equation (12):

$$q = \frac{T_{pi} - T_{pe}}{\frac{1}{2\,\pi\,\lambda\,L}\, ln\frac{r_e}{r_i}} \tag{12}$$

knowing T_{pe}, the Grashof number can be evaluated as well as the Nusselt number. It was then estimated an average outer convective coefficient equal to 625 W/m²K. The exchange coefficient of the tube can be, finally, calculated by the formula (13):

$$h_{tubo} = \frac{\lambda}{r_i \ln\left(\frac{r_e}{r_i}\right)} \tag{13}$$

And it is equal to 19128 W/m²K.
Then for the theoretical coefficient of heat exchange of the coil results an average value of 539 W/m²K
The trend achieved for the simulated K results to be very similar to the real one.
To correct the result and make sure that the simulation is reliable several attempts were carried out modifying the geometric parameters of the tank. It was discovered that the tank has an answer identical to the real one the volume of the tank and the length of the coil will be reduced by about 17% compared to the initial values. By entering a value equal volume of 0.65 m³ tank and the coil length of 25 m the results showed from Figure 36 to Figure 40 were obtained.

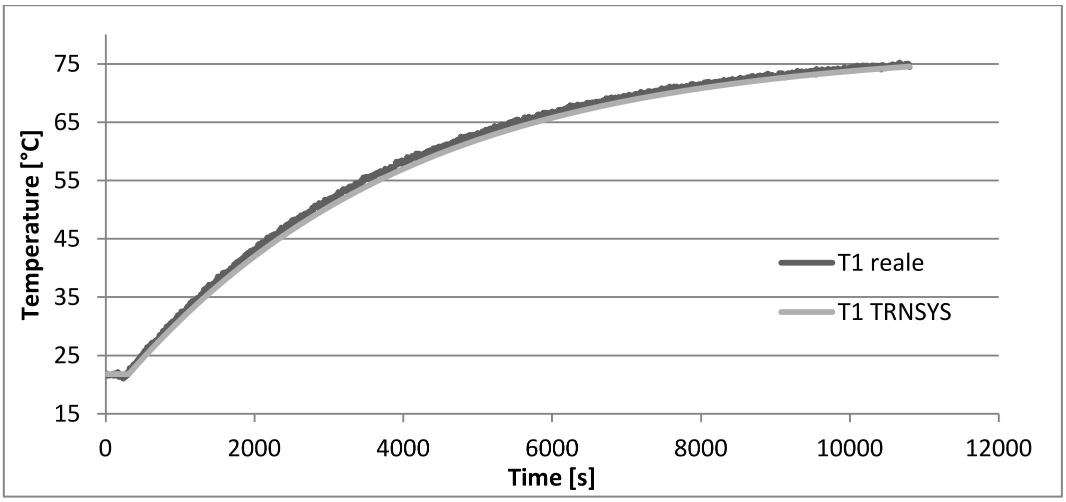


Figure 36. T1 temperatures comparison after the calibration of the Test 1

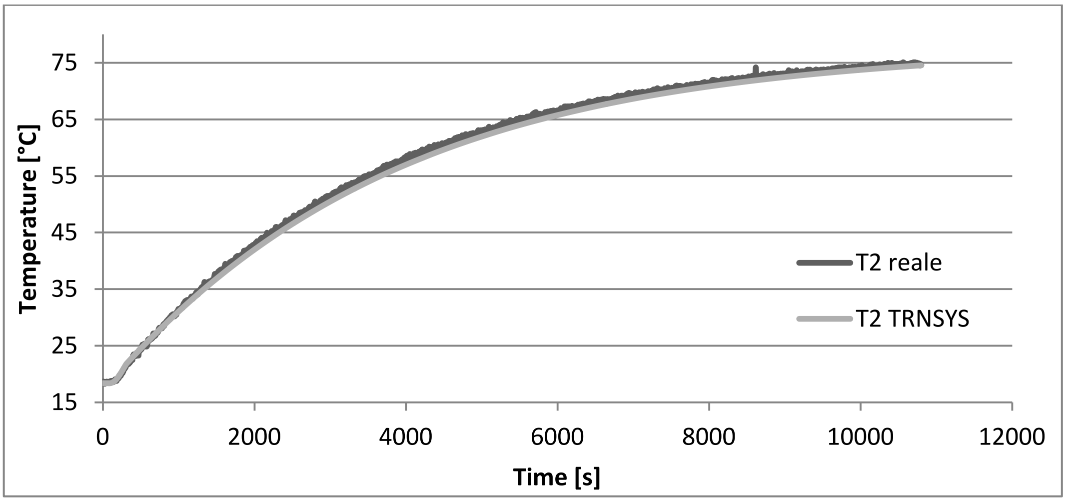


Figure 37. T2 temperatures comparison after the calibration of the Test 1

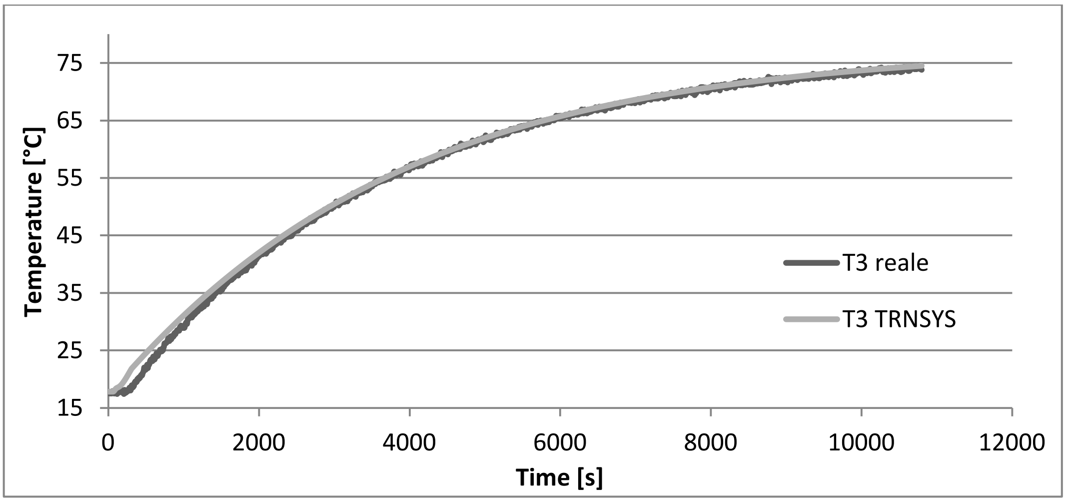


Figure 38. T3 temperatures comparison after the calibration of the Test 1

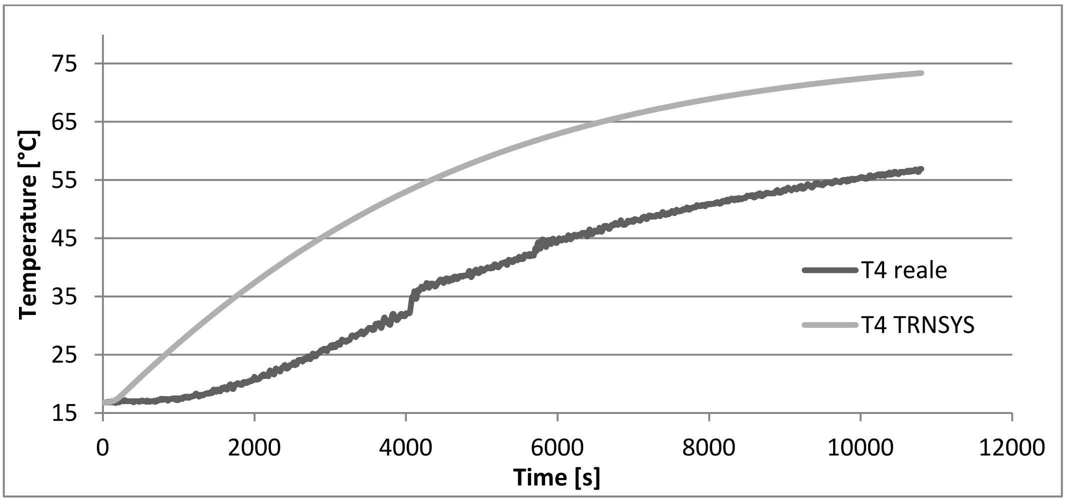


Figure 39. T4 temperatures comparison after the calibration of the Test 1

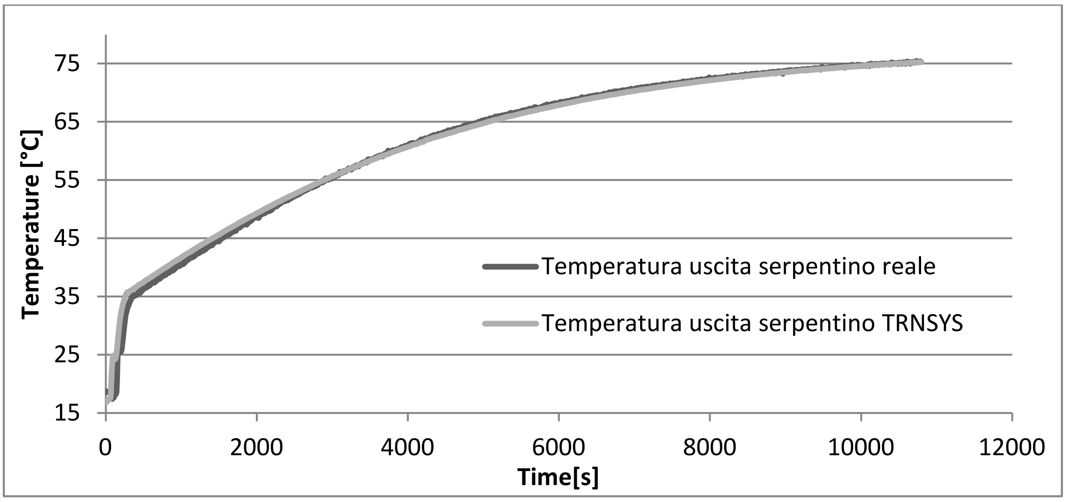


Figure 40. Coil outlet temperatures comparison after the calibration of the Test 1

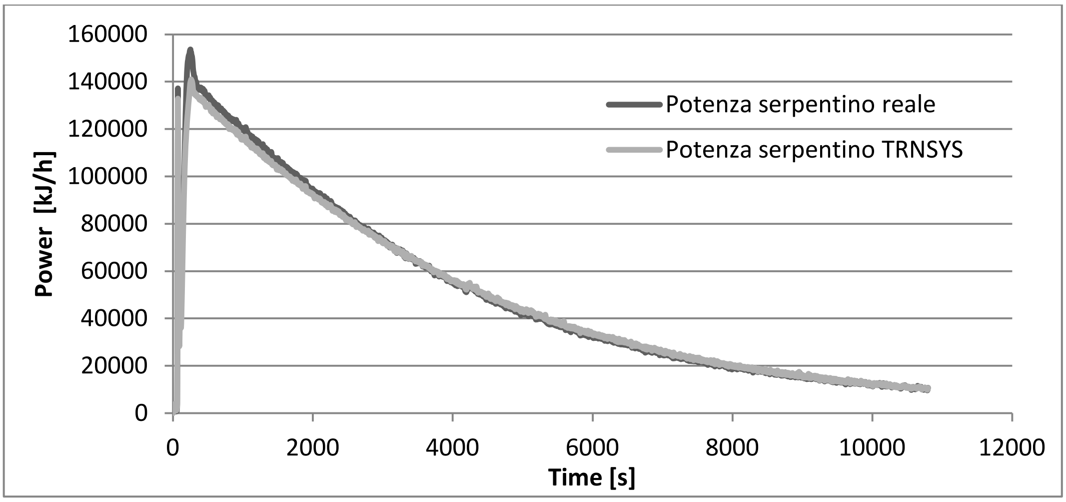


Figure 41. Coil power temperatures comparison after the calibration of the Test 1

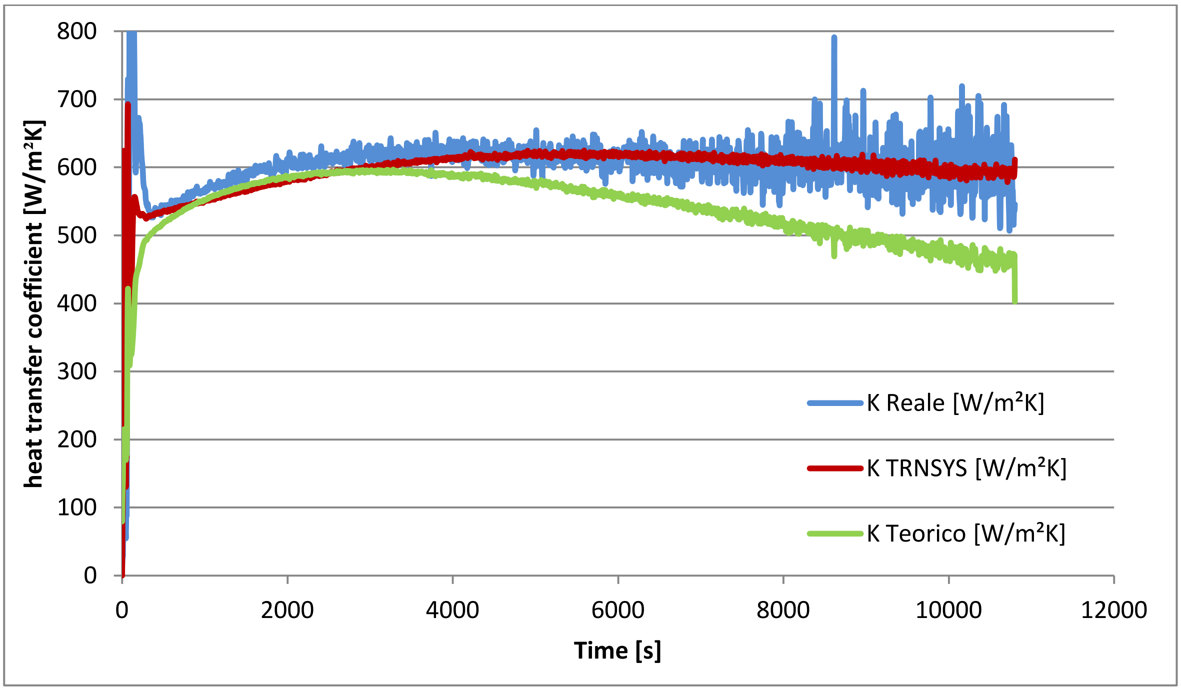


Figure 42. Heat exchange coefficient comparison after the calibration of the Test 1

As a further confirmation of what was said even the performance of the thermal transmittance showed a perfect compatibility between the real and the simulated case.
Particular attention has been paid to the calibration of the heat exchanger coil as it is the purpose of this thesis to optimize as much as possible the solar system. A well-calibrated virtual system allows to have a better meet between the simulated and real behavior and assure that the logic of heat exchange between the solar system and storage have been simulated correctly.

A.2.2 Test 2: temperature drop test with accumulation initially balanced

This Test was performed in order to analyze the phenomenon of heat loss between the thermal storage and the environment. In the test after all the water in the tank was stabilized at the temperature level shown in Table 172 the storage has been let cool down and temperatures, provided by the probes immersed in the inner volume, were acquired for the further 12 hours.

Table 172. Initial conditions and parameters of the Test 2

Item	Value
T1 initial	70,4 °C
T2 initial	71,4 °C
T3 initial	70,4 °C
T4 initial	69,6 °C
Average ambient temperature	22 °C
duration of test	12 h
Range data acquisition	20 sec

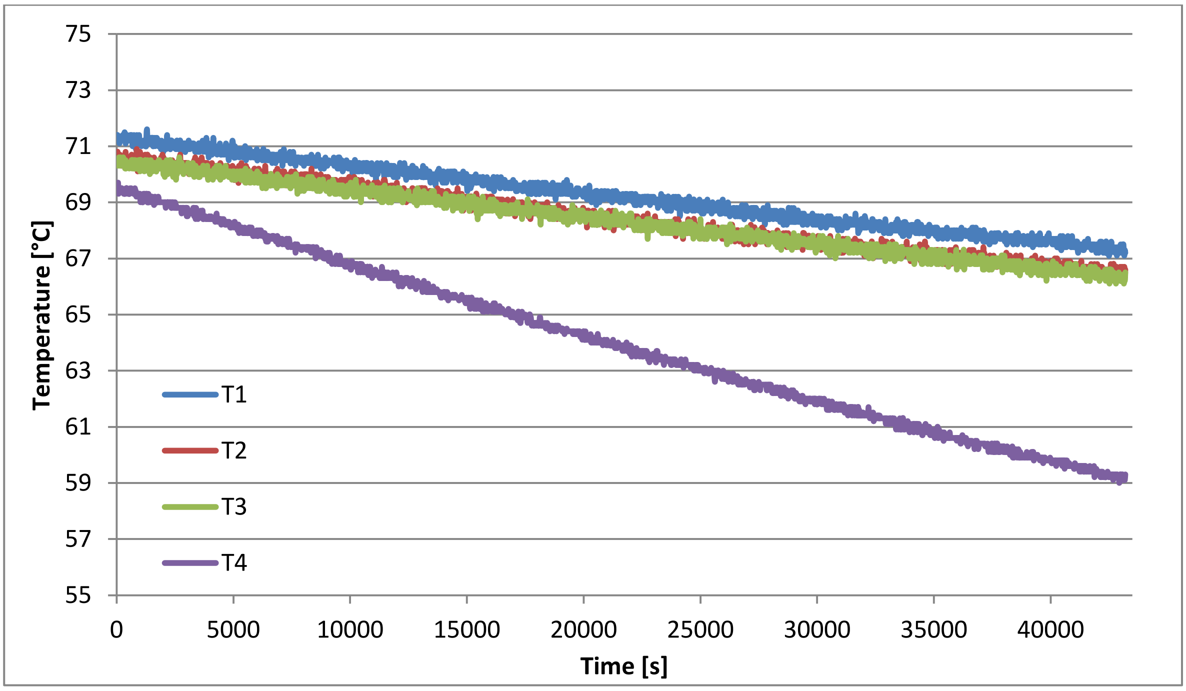


Figure 43. Results of the Test 2

To make a correct simulation of the thermal dispersion, TRNSYS requires that they be supplied loss ratios expressed in kJ/m² K h relative to the top, sides and bottom of the tank. These coefficients coincide with the coefficients of global heat exchange of the walls of the tank. The accurate estimation of these coefficients is obtained using the Equation (14):

$$K = \frac{1}{\frac{1}{\alpha_i} + \frac{1}{h_{parete}} + \frac{1}{h_{isolante}} + \frac{1}{\alpha_e}} \tag{14}$$

the heat transfer coefficient and wall insulation can be easily calculated known their characteristics through the equation (15):

$$h_{parete} = \frac{\lambda}{s} \tag{15}$$

To estimate the coefficients convective internal and external tank is necessary to know the temperature of the wall of the reservoir which, however, are unknown.
In first analysis the simulation has been carried out with the software default value for the heat loss coefficients of the tank, equal to 1,5 kJ/h m²K. Knowing that the thickness of the insulation layer is 100 mm and that it is made by soft polyurethane, which has a conductivity of 0.038 W/mK , by a heat transfer coefficient of 0.38 W/m²K is obtained which is equal to 1.37 kJ/m²hK.
Results of the carried simulations are presented in graphs from figure to .

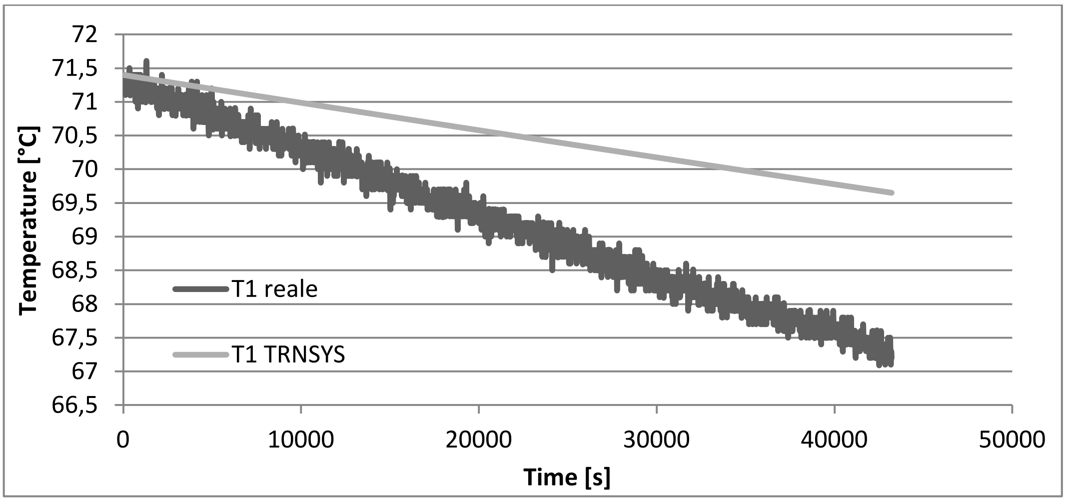


Figure 44. T1 temperature comparison Test 2

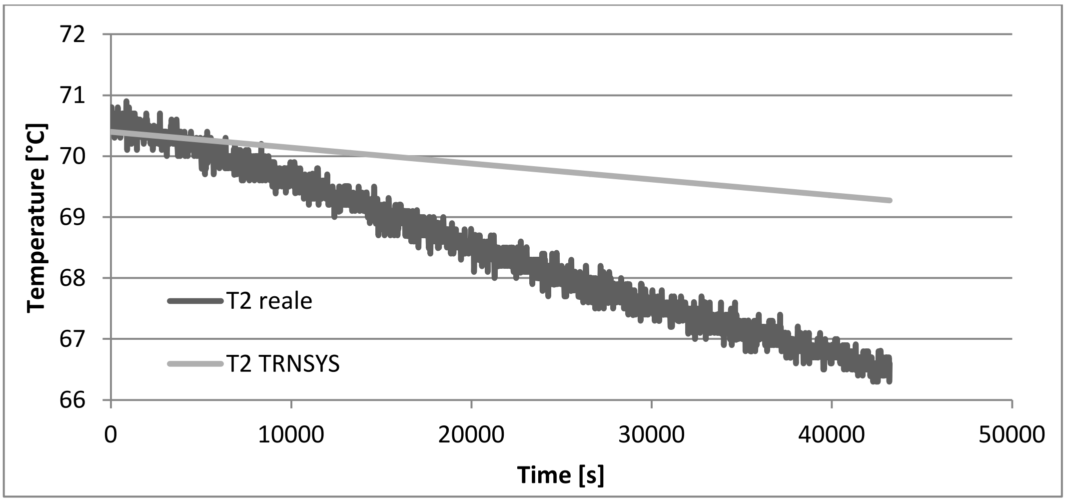


Figure 45. T2 temperature comparison Test 2

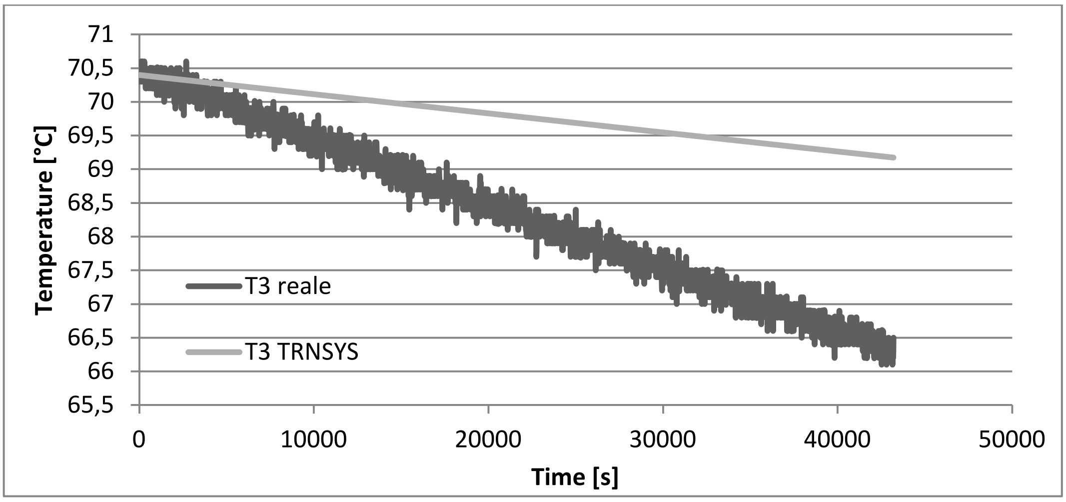


Figure 46. T3 temperature comparison Test 2

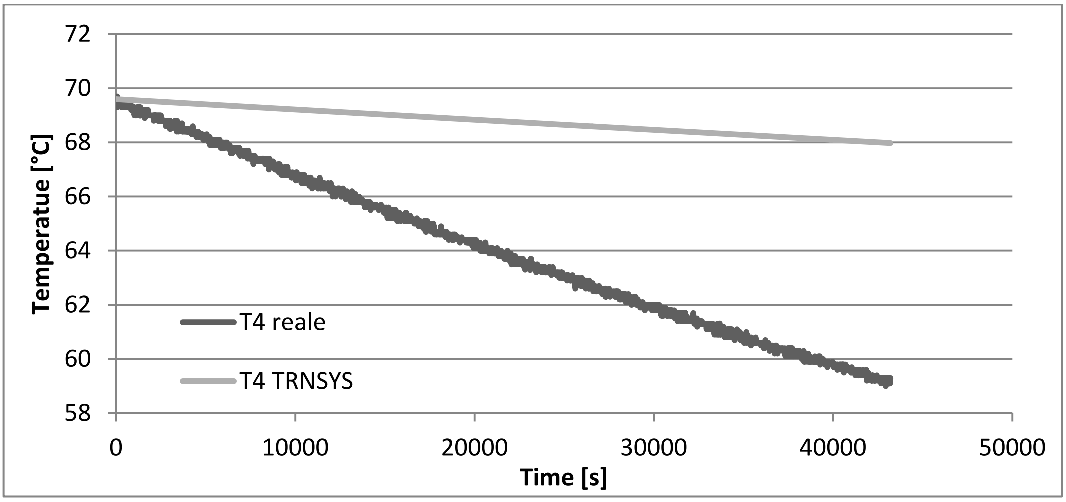


Figure 47. T4 temperature comparison Test 2

The results show a marked difference between the real and the estimated temperature, in fact, the simulated temperature tends to vary with a lower gradient. This indicates that the value assumed for the default loss coefficients are too low.

Figure 47 shows a difference more accentuated to node 4, in fact it presents an average difference between the two temperatures of 4.8 °C and a maximum difference of 9°C, more than triple respect to the other nodes . It is hypothesized that this is due to two main causes. The first explanation is that the tank is not well insulated at the bottom and during the test, it was placed on a pallet and not in contact with the floor. This has generated a convective phenomena which have increased thermal dispersion of the lower part of the tank. The second cause is due to the fact that the temperature probe is not positioned in the central part of the tank but in the proximity of the wall (as already said due to the presence of the coil). During the cooling phase, it has been considered a temperature measured close to the wall instead that the inner volume one.

Table 173. Thermal losses coefficientS

Item	Value
Top thermal losses coefficient	1,5 kJ/hm²K
Edge thermal losses coefficient	5 kJ/hm²K
Bottom thermal losses coefficient	22,5 kJ/hm²K

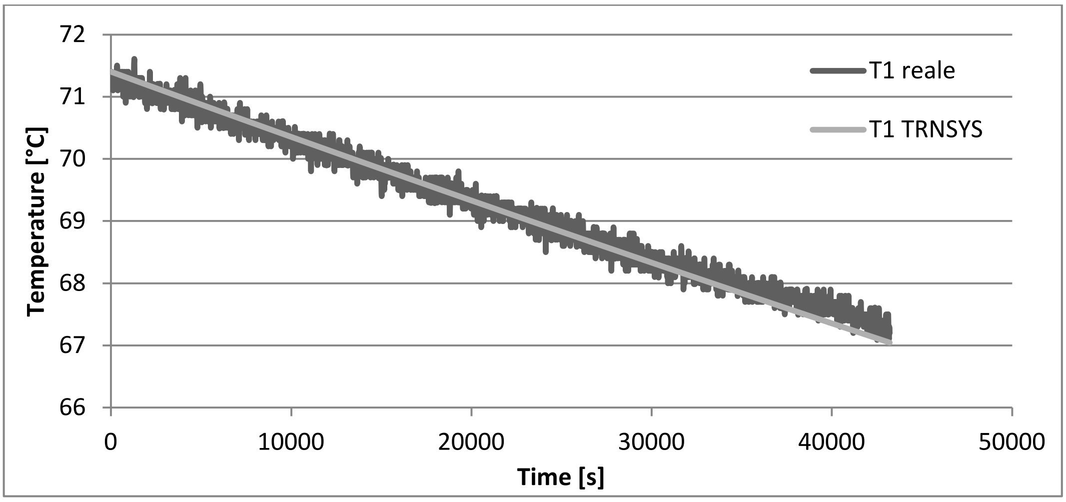


Figure 48. T1 temperature comparison after the calibration of the Test 2

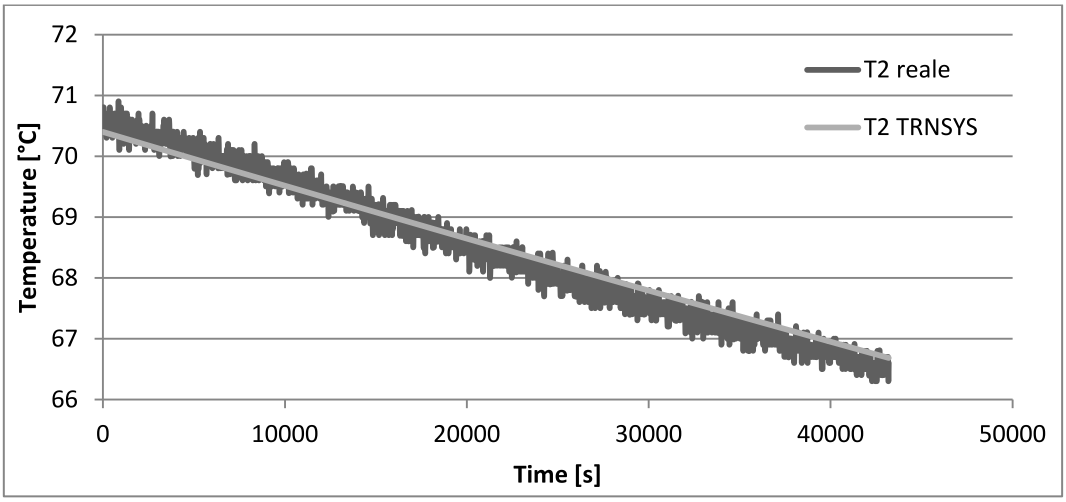


Figure 49. T2 temperature comparison after the calibration of the Test 2

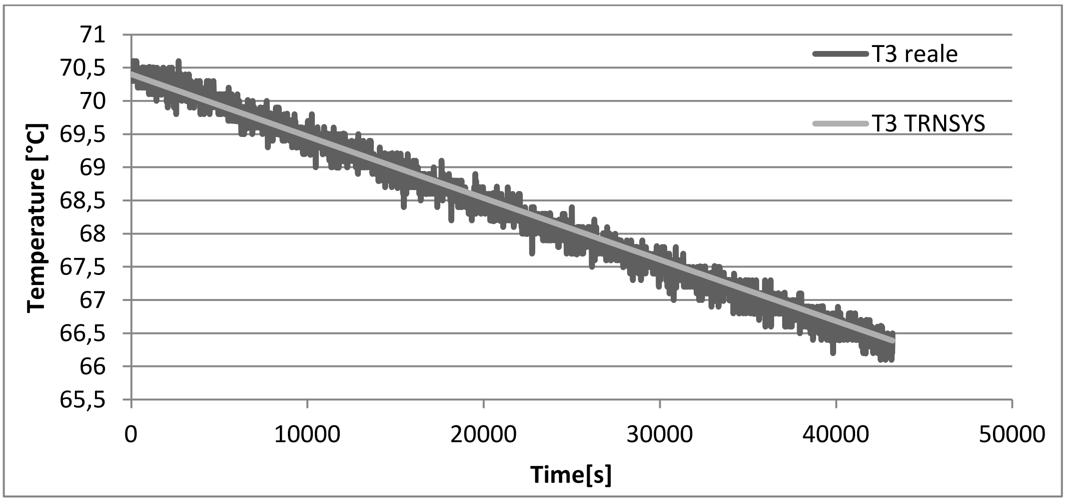


Figure 50. T3 temperature comparison after the calibration of the Test 2

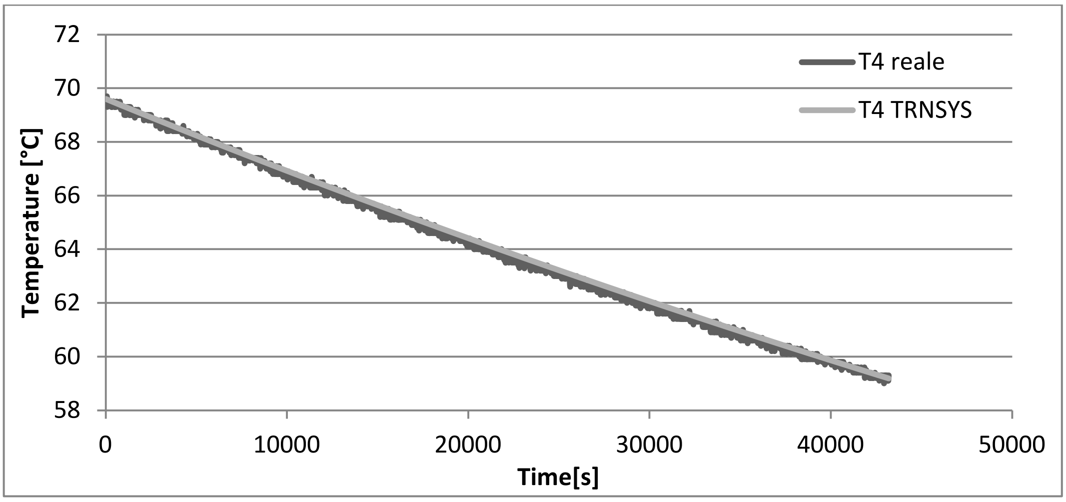


Figure 51. T4 temperature comparison after the calibration of the Test 2

As it can be seen after the calibration the temperature trends are similar enough to be considered almost identical. In confirmation of what has been said before, the heat loss coefficient at the bottom of the tank is significantly increased compared to the former value and it can be seen how it is greater in comparison to the values of the other section of the tank. This variability makes difficult to estimate the real bottom heat exchange coefficient, especially considering that in the real application the storage will be placed directly on the basement and not on a pallet. given that in a practical application of the same tank is placed on the floor. The coefficient of the upper part has not been changed since it has a greater insulation and it is assumed a lower dissipation for convective phenomena.

A.2.3 Test 3: Heating by means of the upper nodes

This test wants to replicate the heating of the thermal storage by the means of the boiler circuit, generally connected through at the upper nodes of the tank. The hot water flow come into the storage through the port E1 (Figure 52), and mixing with the inner volume cause the raising of the temperature of the upper nodes of the tank. At the same time an equal flow rate is draw from the tank to the boiler through the port E2.

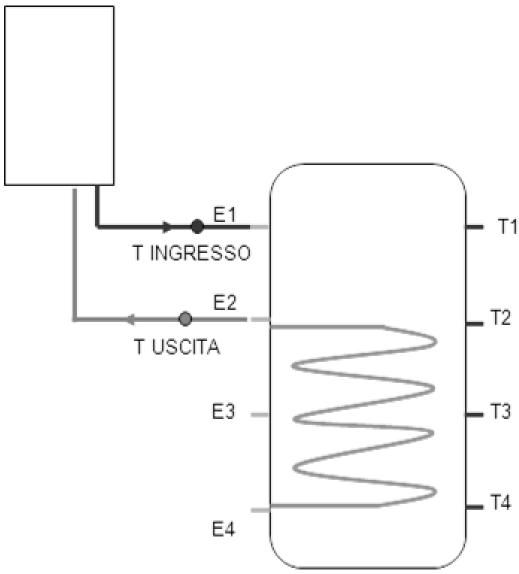


Figure 52. Test 3 facilities

During the test 3 the same entities of the test 1 have been recorded, they are presented Figure 53, while the Table 174 provides the initial condition of the test.

Table 174. Initial condition for the Test 3

Item	Value
T1 initial	34,1 °C
T2 initial	34,2 °C
T3 initial	33,7 °C
T4 initial	34,3 °C
Average ambient temperature	21,9 °C
Boiler temperature set point	50 °C
Average flow boiler	750 1/h
Duration of test	49 min
Range data acquisition	5 sec

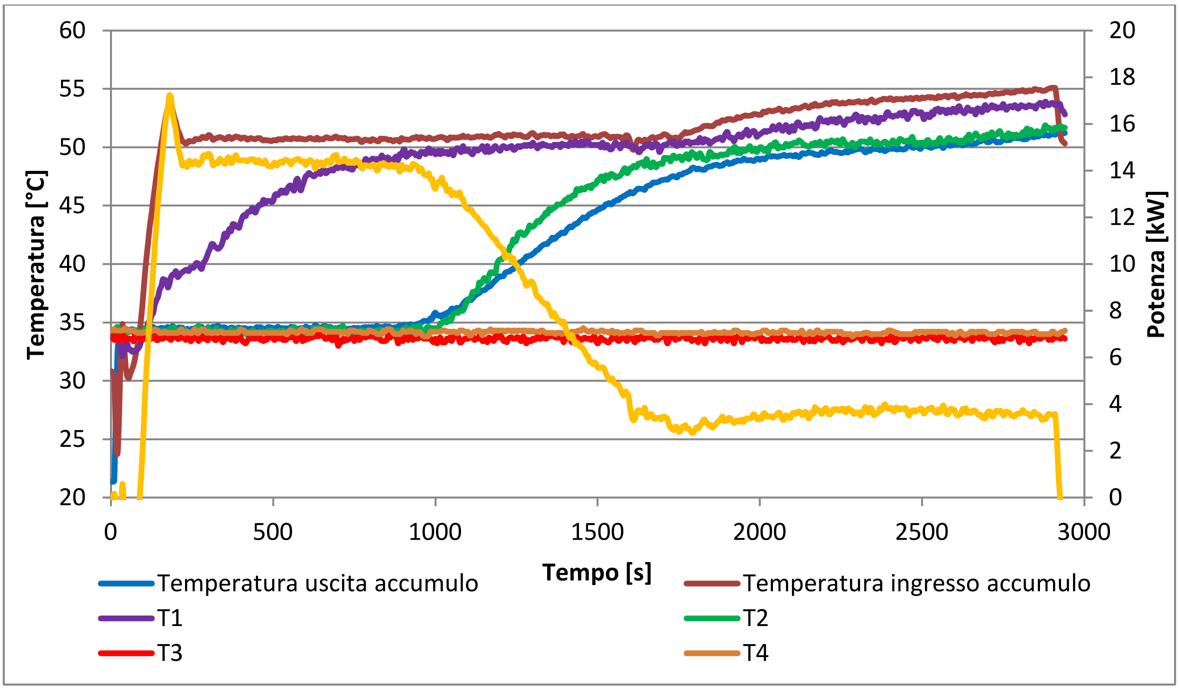


Figure 53. Results of the calibration of the test 3

Unlike what was done previously it was not possible to realize a proper calibration for his test because the user can not intervene to alter the mechanical or thermal properties that the software TRNSYS uses to handle these types of heat exchanges. Despite this, the comparison between the real and the simulated case can highlight some important aspects on the functioning of the tank. The input data for the simulation are the temperature and the flow rate at the inlet E1, values set according to the measurements.

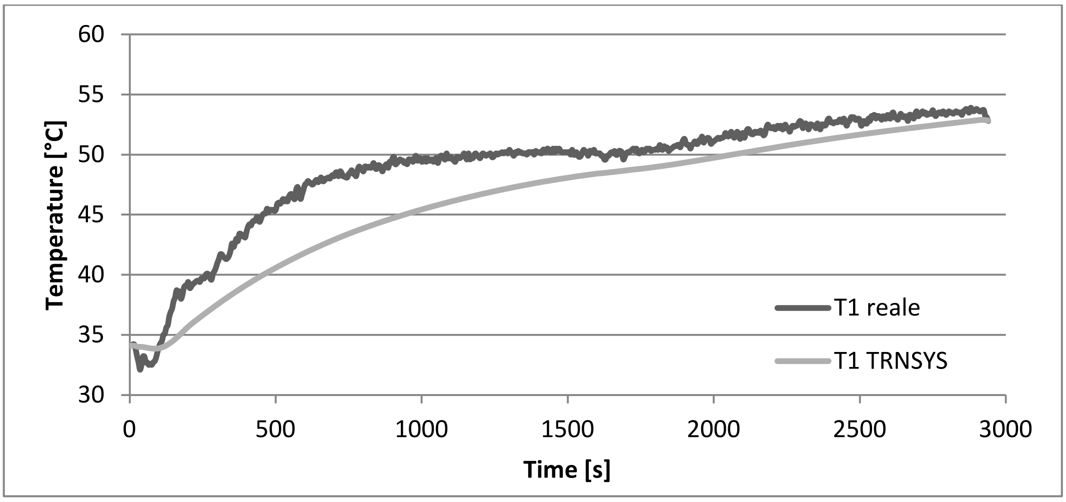


Figure 54. T1 temperature comparison for the Test 3

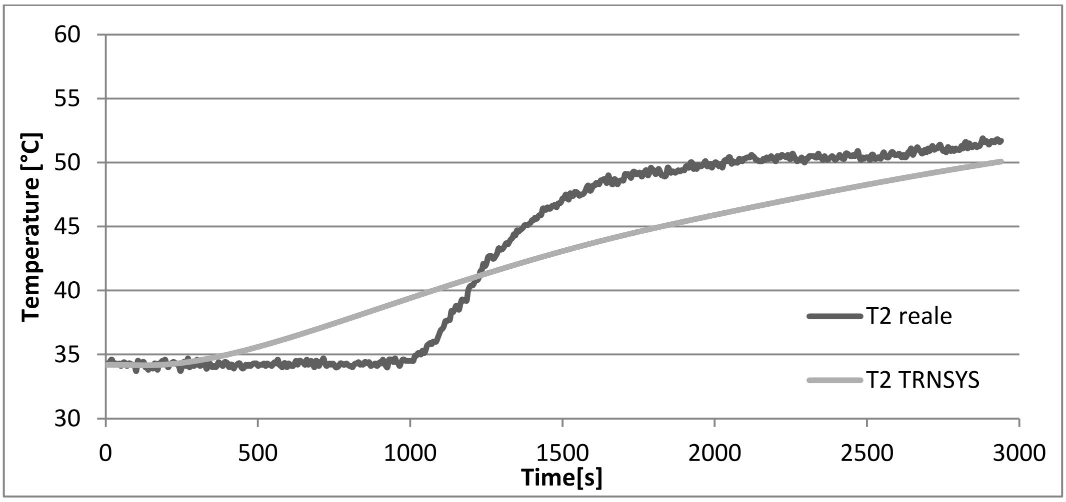


Figure 55. T2 temperature comparison for the Test 3

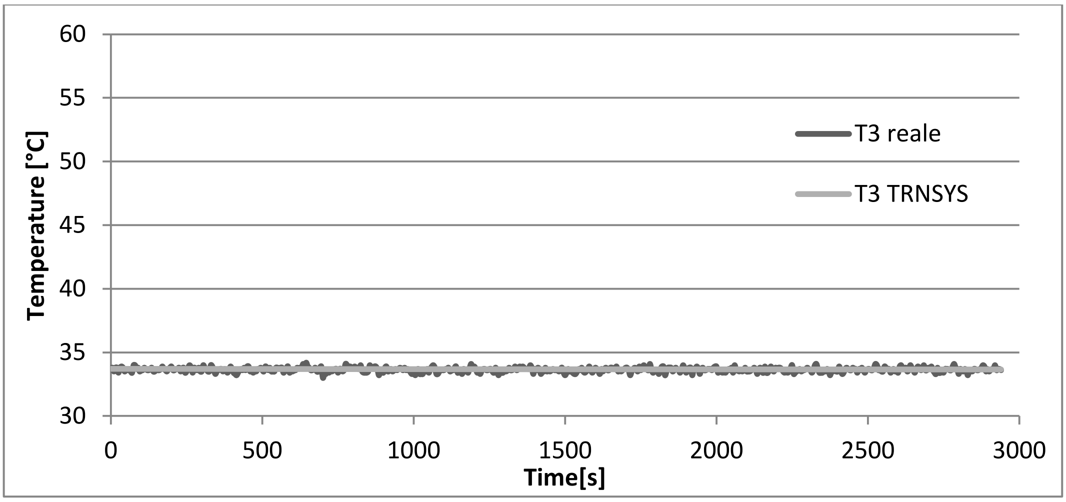


Figure 56. T3 temperature comparison for the Test 3

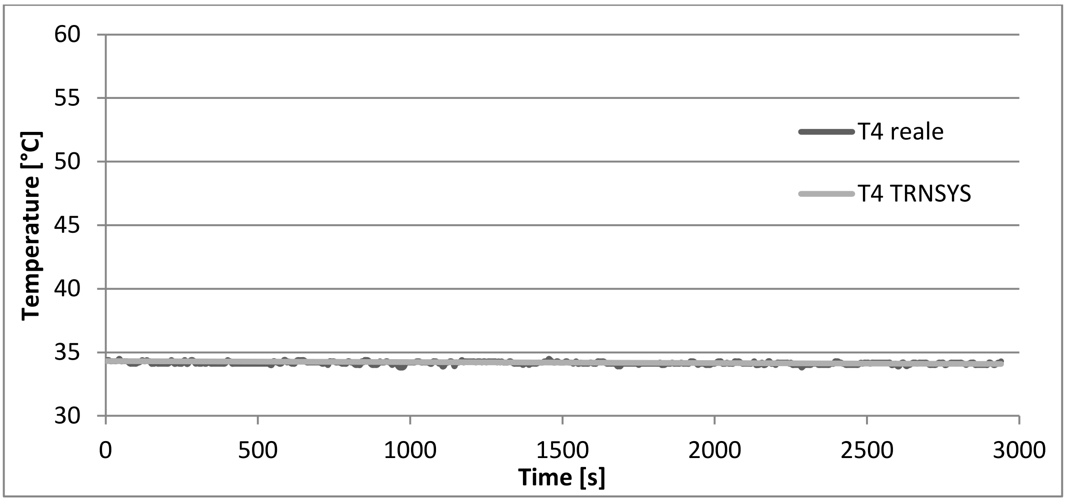


Figure 57. T4 temperature comparison for the Test 3

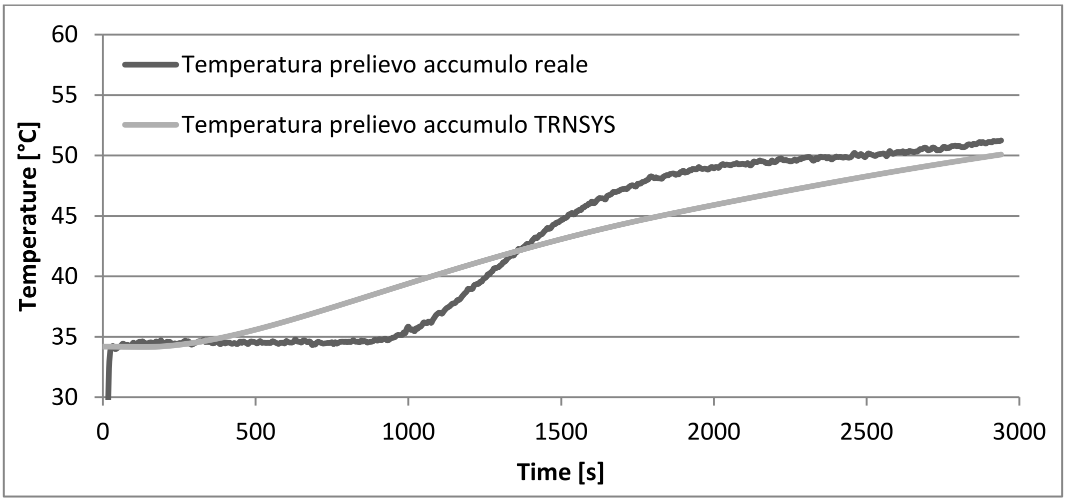


Figure 58. Outlet temperature comparison for the Test 3

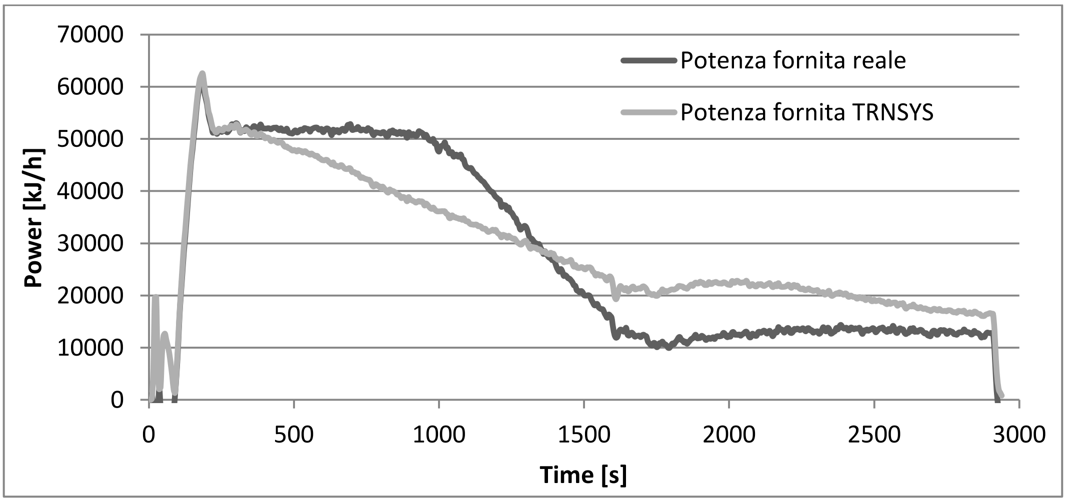


Figure 59. Power comparison Test 3

As can be seen from the figures, the performance of the simulated case approximates generally quite faithful to the real case. The main difference lies in the fact that the software has a slower and less abrupt response to the stresses imposed by the heating circuit, because the variations of the temperature at the outlet from the accumulation are more gradual. This trend is due to a different fluid flow dynamic behavior according to the simulated tank respect to the real one. In fact, as it was said, inside the tank at each junction baffles are present which have the purpose to direct the flow at the inlet and at the drawn. The baffles are all arranged with a downward inclination as in Figure 60 except for the two upper connections in which the two deflectors are reversed by 180° and places upward.
The provision of such devices obliges the incoming flow to travel along a different and longer direction compared to that calculated in the simulation, in this way the variation of the temperature at the outlet from the tank is more decisive than in the case without tile provided by the simulator.

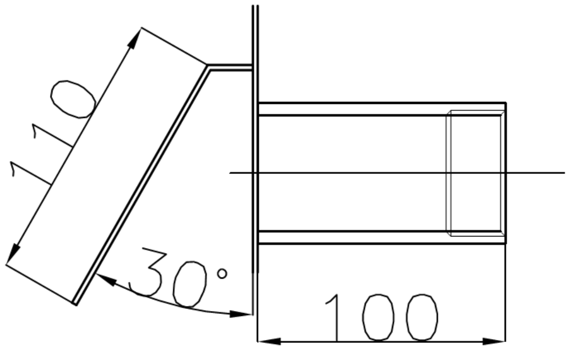


Figure 60. Tank Baffles

It is known as the heating Tends to Affect only the upper layers while the lower ones do not undergo significant to temperature variations. From the numerical results it was observed that the total energy exchanged in the real case and in the case simulated are almost identical, respectively equal to 376 kWh 398 kWh. As regards the outlet temperature, between the measured and the simulated value, after approximately 45 minutes of test it was achieved a difference equal only to 1°C, and this confirms that despite what conservatively has been said above, the simulation can be considered suitable.

A.2.4 Test 4: Thermal Drop Test with heat stratified storage tank.

The test described in this paragraph is very similar to the Test 2, the main difference lies in the fact that the entire mass of water contained in the tank has not been brought to the same initial temperature but at the initial conditions showed in Table 175, obtained at the end of the previous test. The purpose is to observe how the thermal losses occur within the thermal storage when it is in a condition of thermal stratification.

Table 175. Initial conditions and parameters for the Test 4

Item	Value
T1 initial	52,1 °C
T2 initial	51,6 °C
T3 initial	33,7 °C
T4 initial	34,1 °C
Average ambient temperature	22,4 °C
Duration of test	12 h
Range data acquisition	20 sec

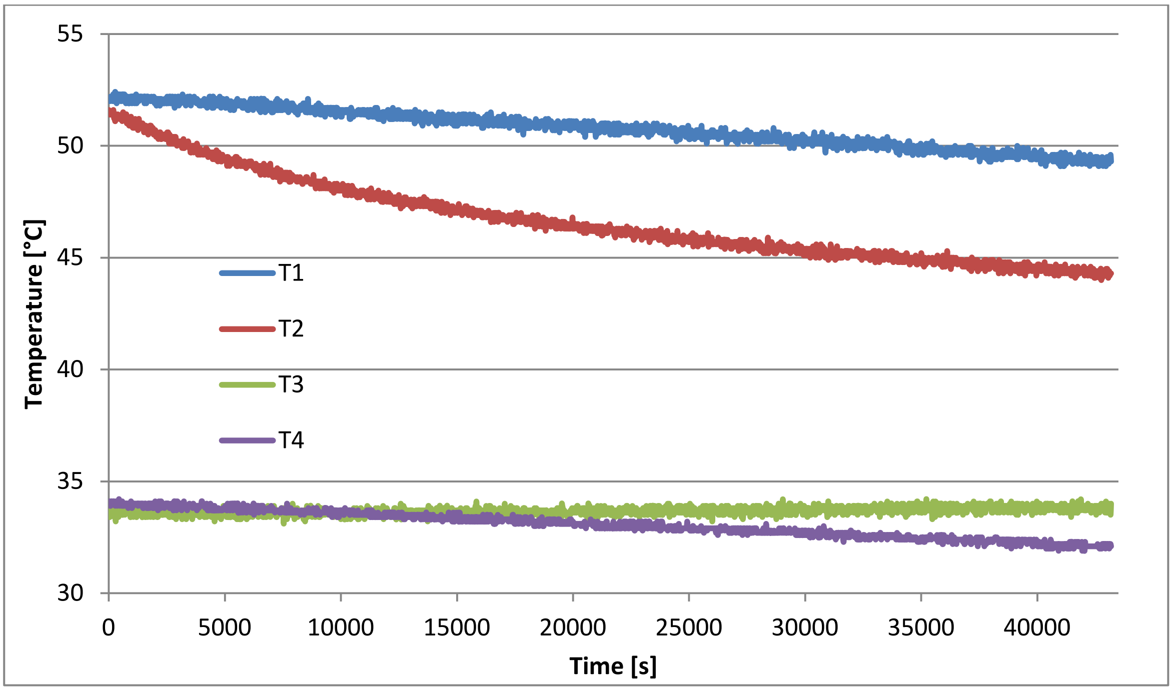


Figure 61. Results of the Test 4

The results presented in the following graphs showed an increase in the real case temperature registered by the probe in the junction 3. This heating is due to a phenomenon of internal heat exchange between the upper layers of the hottest and coldest lower ones having a Δt of about 20 °C. The results presented in the following Figures showed a temperature raising of the measurement of the probe place at the junction 3, due to a heat exchange between the upper nodes of the tank and the lower ones, being the temperature difference within the inner volume equal to 20°C. The software, because of the model through which elaborates the mass and energy balances within the tank, underestimates the heat exchanged by flow mixing. It is possible to fix this inconvenience adjusting ad index properly conceived for the purpose.

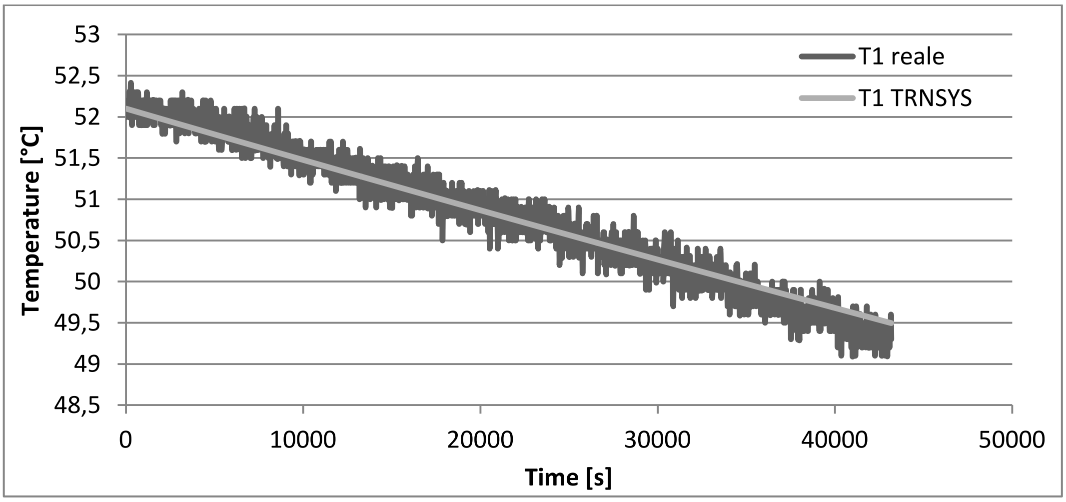


Figure 62. T1 temperature comparison for the Test 4

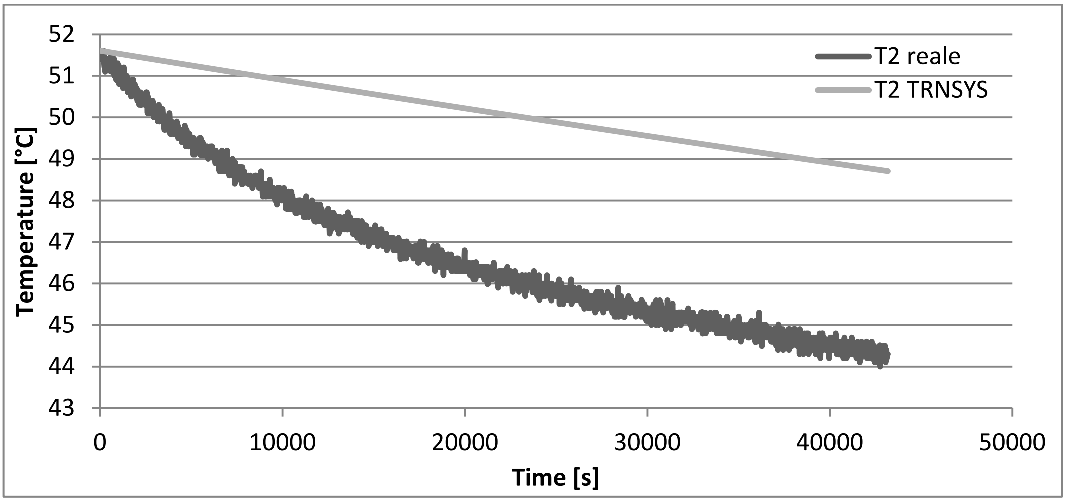


Figure 63. T2 temperature comparison for the Test 4

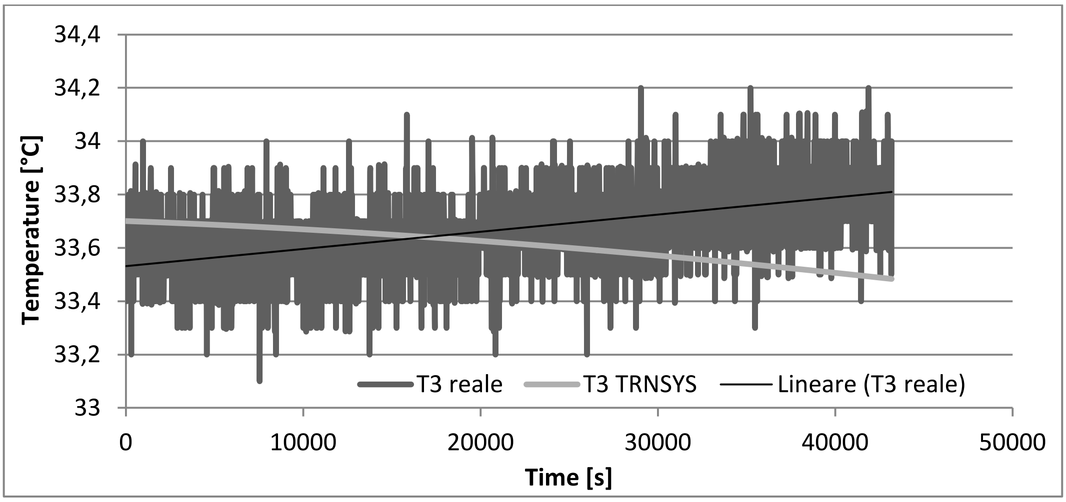


Figure 64. T3 temperature comparison for the Test 4

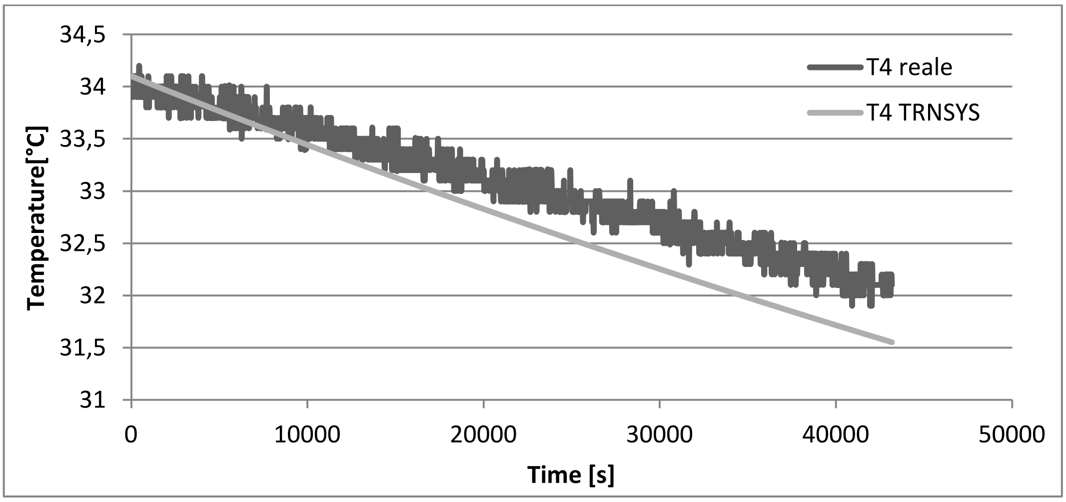


Figure 65. T4 temperature comparison for the Test 4

A.2.5 Test 5: Heating by means of the upper nodes and drawn from the junction E1

This test aims to evaluate the behavior of the tank during the contemporary heating through the upper nodes and a hot flow withdrawal. The boiler is connected according to the Figure 66 to the junctions E1 and E2.

The other side of the tank has been executed a withdrawal in order to simulate the presence of a radiant system. The flow temperature of the radiant system is controlled by a thermostatic valve that mixes the water out of the tank with the temperature of the return line. To manage such a system the ramps described in paragraph A.1 have been used. One ramp discharged a hot water flow to heating the storage (boiler emulation) in order to obtain an outlet temperature value, set by the valve, equal to 38 °C, the other ramp was operated as the return of the radiant system to provide to the tank a flow at the temperature of 33 °C. So the radian system was simulated to achieve a temperature difference of 5 °C between the delivery and the return circuits.

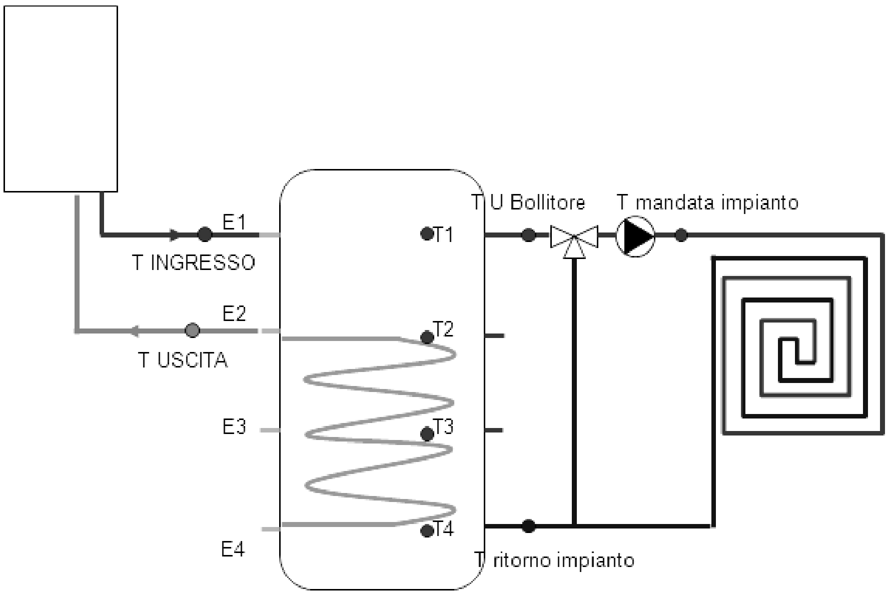


Figure 66. Test 5 facilities

Initial conditions and results of the test are provided in Table 176.

Table 176. Initial conditions Test 5

Item	Value
T1 initial	47,5 °C
T2 initial	48,6 °C
T3 initial	26,7 °C
T4 initial	26,2 °C
Average ambient temperature	17,8 °C
Boiler temperature set point	50 °C
Average flow boiler	750 l/h
Temperature set point thermostatic valve	38 °C
Average flow radiant system	1200 l/h
Duration of test	1 h
Range data acquisition	5 sec

The setting of the test with the software have been realized as shown in Figure 40. The data provided to the model are:

- the inlet temperature of the boiler circuit
- the flow rate of the boiler circuit
- the flow temperature of the radiant system
- the temperature of the radiant system return system
- the scope of the radiant system

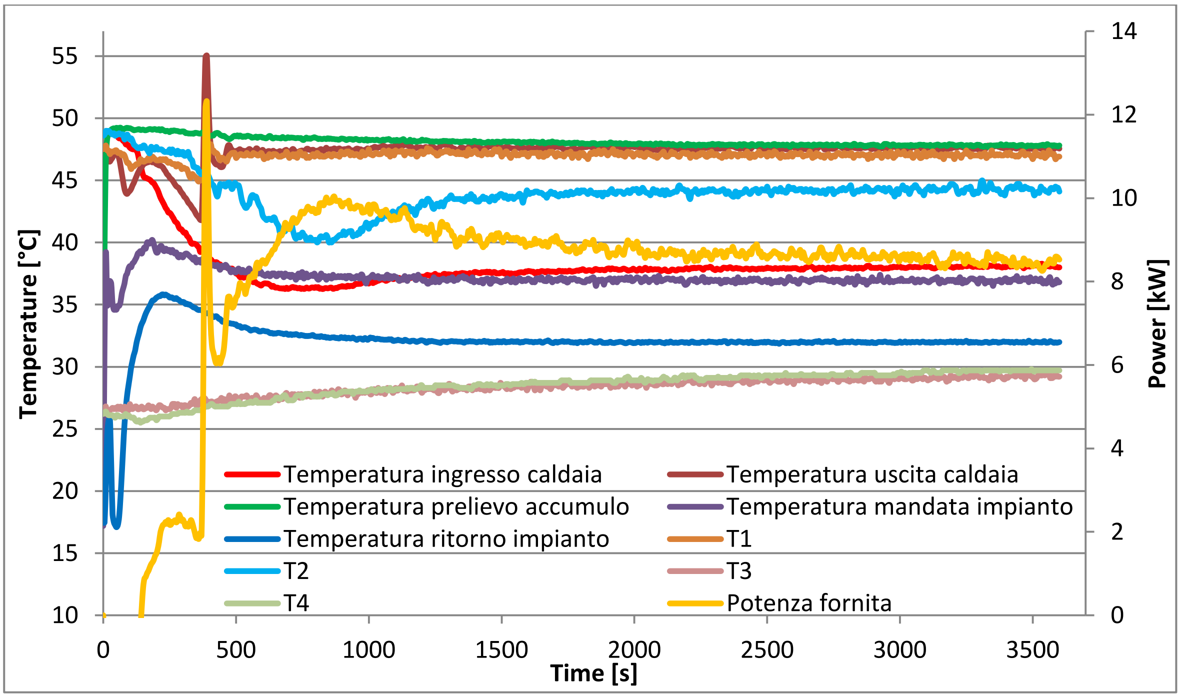


Figure 67. Results of the Test 5

The dynamic simulation provides as results the temperatures values of the tank nodes, the temperature of the outlet water from the tank, the temperature, the flow rate and the power transferred from the boiler.

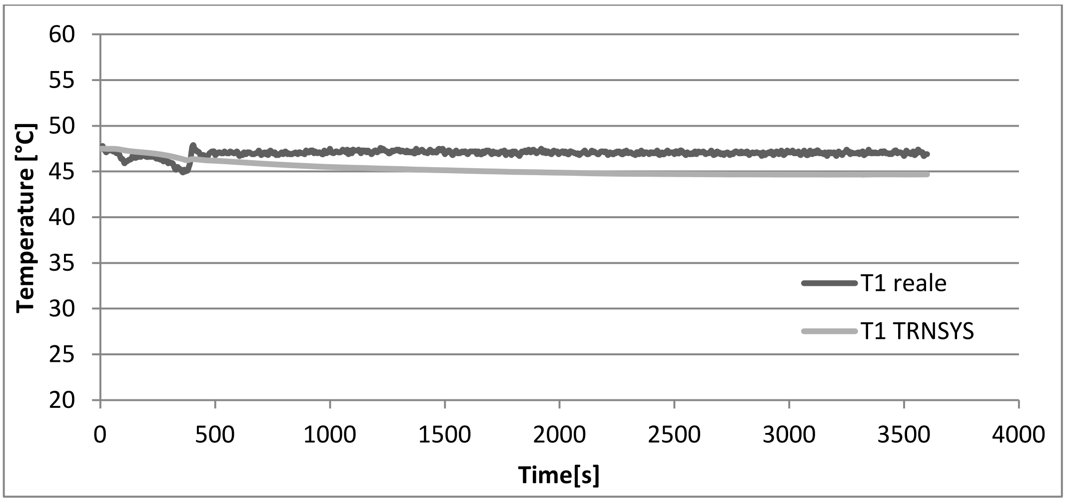


Figure 68. T1 temperature comparison for the Test 5

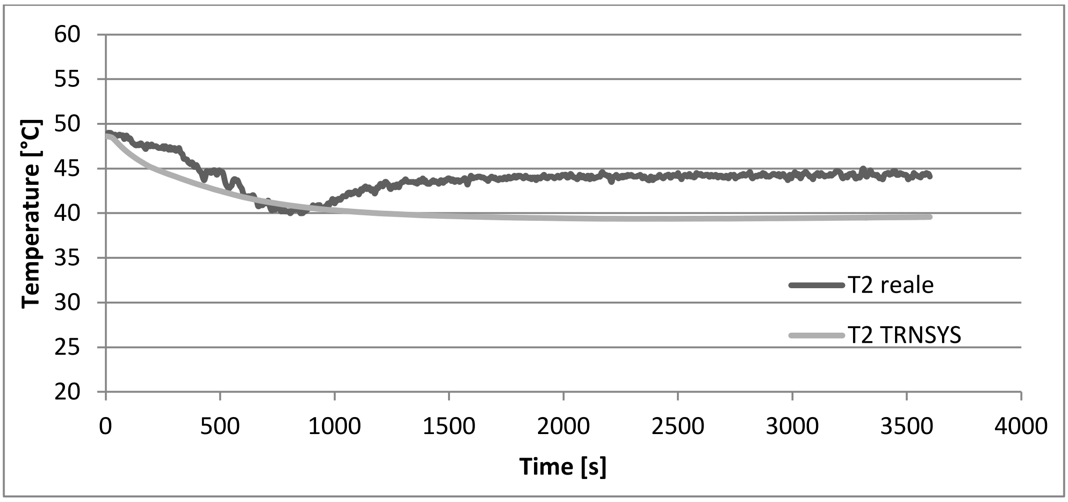


Figure 69. T2 temperature comparison for the Test 5

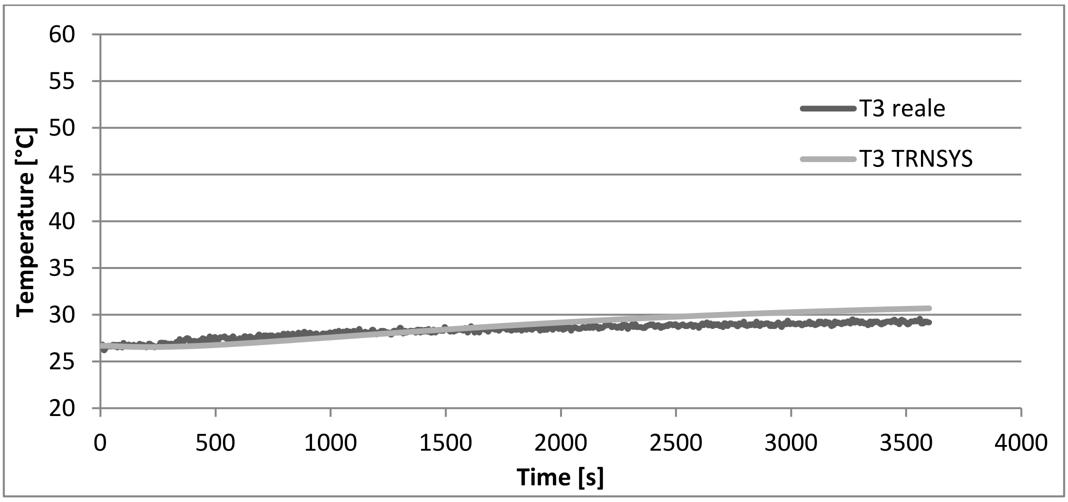


Figure 70. T3 temperature comparison for the Test 5

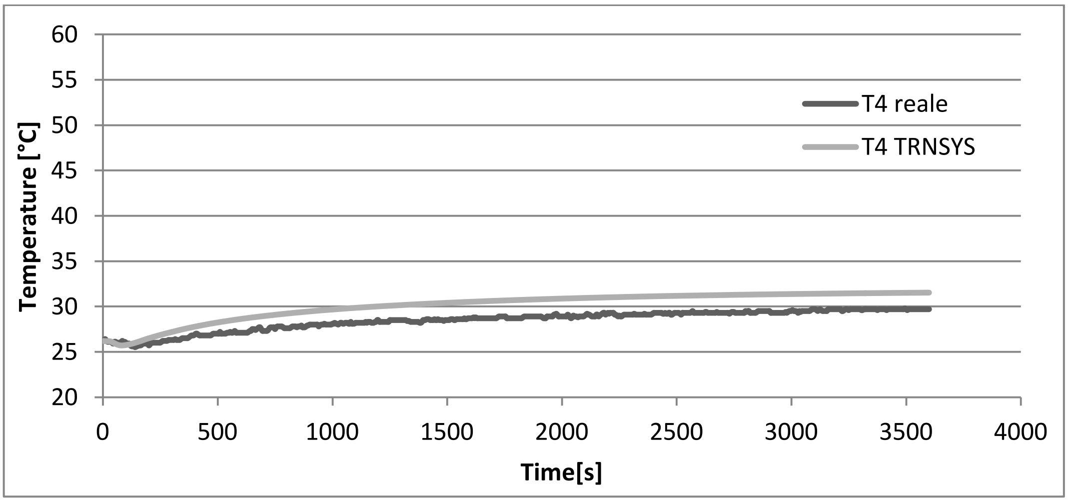


Figure 71. T4 temperature comparison for the Test 5

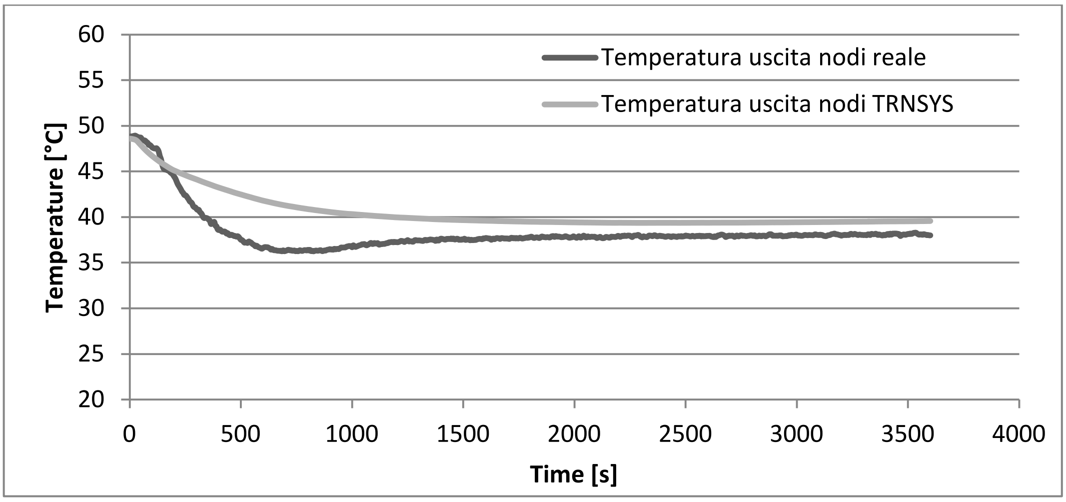


Figure 72. Outlet temperature comparison Test 5

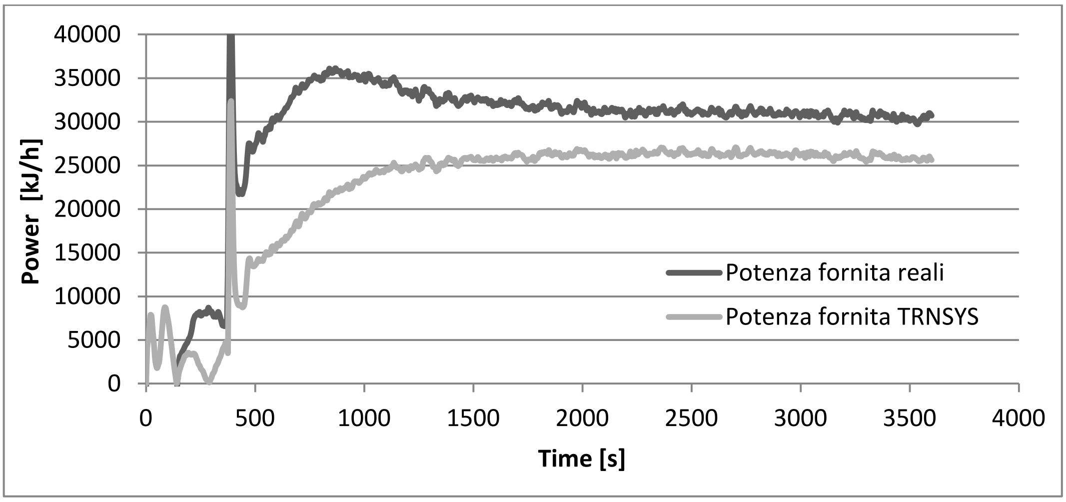


Figure 73. Coil heat exchange capacity Test 5

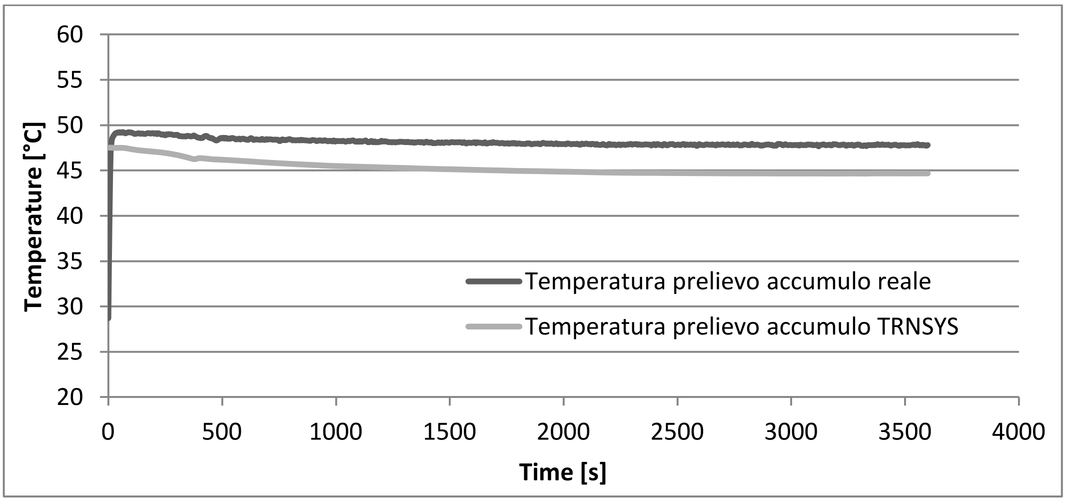


Figure 74. Withdrawal flow temperature comparison Test 5

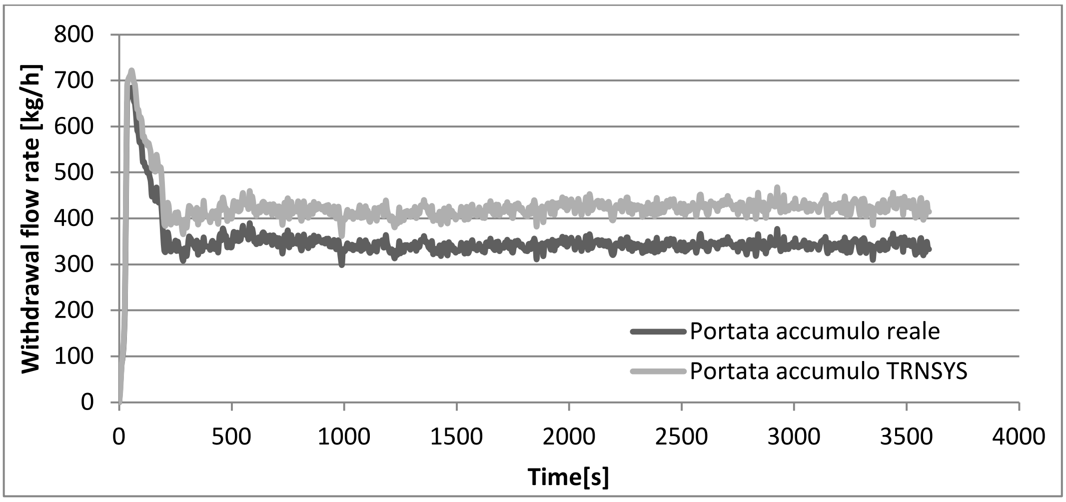


Figure 75. Withdrawal flow rate comparison Test 5

The analysis of the temperatures at the nodes showed a differences between the nodes 1 and 2 . The graphs of Figure 68 and Figure 69 show how the temperature in the real case is about 2 °C higher than the simulated one . This can be explained by the presence of the baffles. In fact the two deflectors are placed in the upper position where there is the attack of inlet water coming from the boiler and the attack of the draw of the radiant system, they are inclined upwards and oblige the flow to follow a direction which tends to create a bridge between the two attacks .

In this way, the water coming from the generator flows directly from the entrance to the exit bypassing all the accumulation and maintaining the upper layers at the same temperature of flow from the boiler. This fact is confirmed by the graph of Figure 74 in which it can be observed how the temperature of the water withdrawn is equal to the one of boiler output. The simulation, however, not considering the presence of baffles, during withdrawal draws water from the lower node, which presents a lower temperature. Furthermore, according with the energy balance evaluation procedure implemented in the software, the flows incoming to the same node are completely and instantaneously mixed with the inner volume, so event as thermal bridging cannot be foreseen.

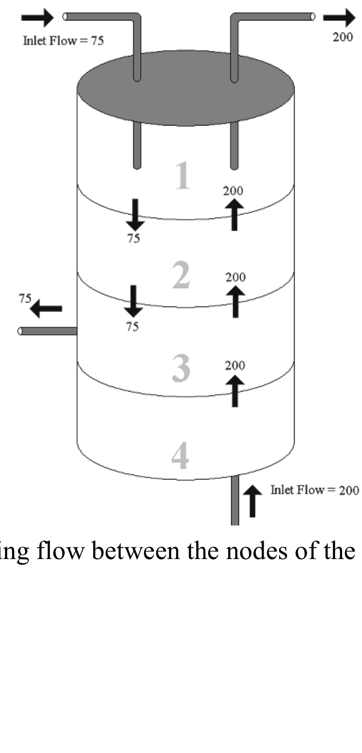


Figure 76. Mixing flow between the nodes of the tank in TRNSYS

The temperature differences observed imply a different function of the real tank respect to the one implemented through the software. In fact, a lower temperature implies a higher flow exiting the heating side (Figure 75) affecting the entire simulation, also a lower return temperature to the boiler also means less power transferred from the generator to the tank compared to the real case. Regarding the lower nodes it can be noticed an acceptable trend of temperatures.

A.2.6 Test 6: Heating by means of the upper nodes and drawn from the junction E2

The setting of this Test is identical to the former one, with the only difference according o the placement of the delivery junction to the radiant heating system. The water withdrawal to feed the radiant plant is connected to the second node E2 and no longer at the top of the tank.

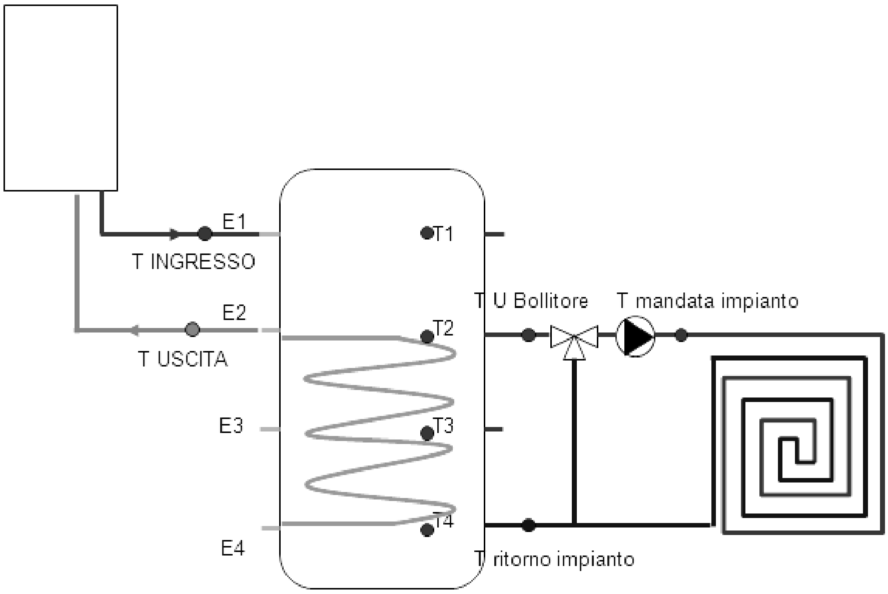


Figure 77. Test 6 facilities

Initial conditions and results of the test are provided in Table 177 and Figure 77.

Table 177. Initial conditions and references for the Test 6

Item	Value
T1 initial	47,1 °C
T2 initial	44,5 °C
T3 initial	29,7 °C
T4 initial	30,3 °C
Average ambient temperature	18 °C
Boiler temperature set point	50 °C
Average flow boiler	750 l/h
Temperature set point thermostatic valve	38 °C
Average flow radiant system	1200 l/h
Duration of test	1 h
Range data acquisition	5 sec

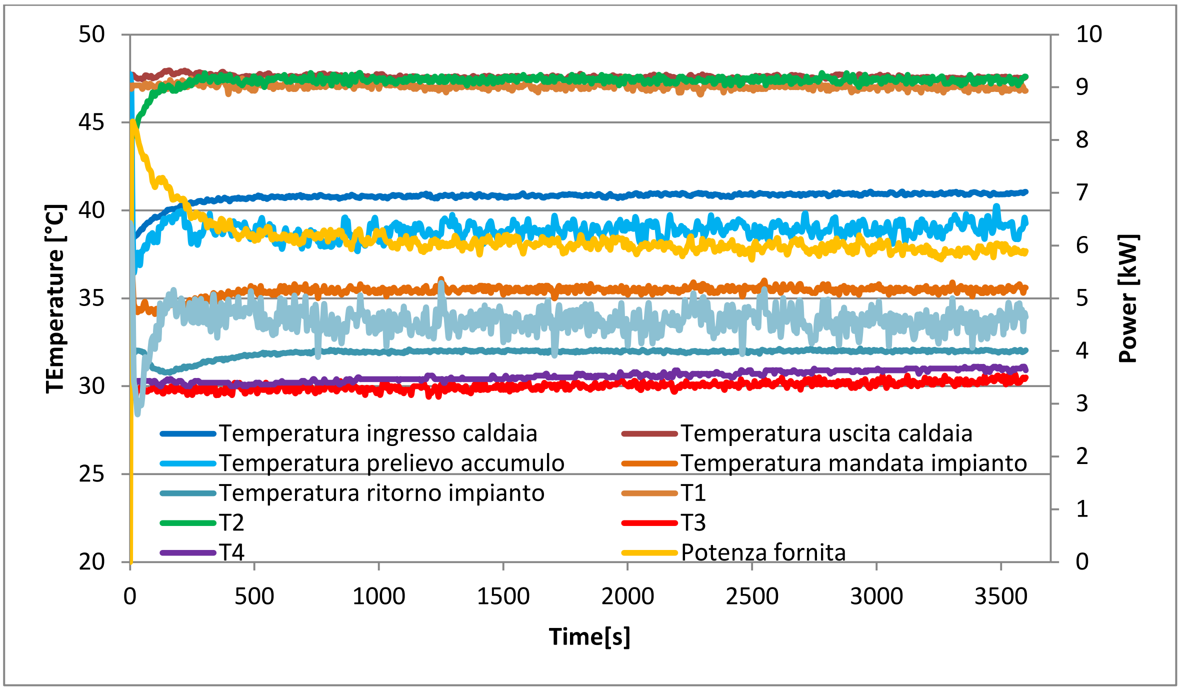


Figure 78. Results of the Test 6

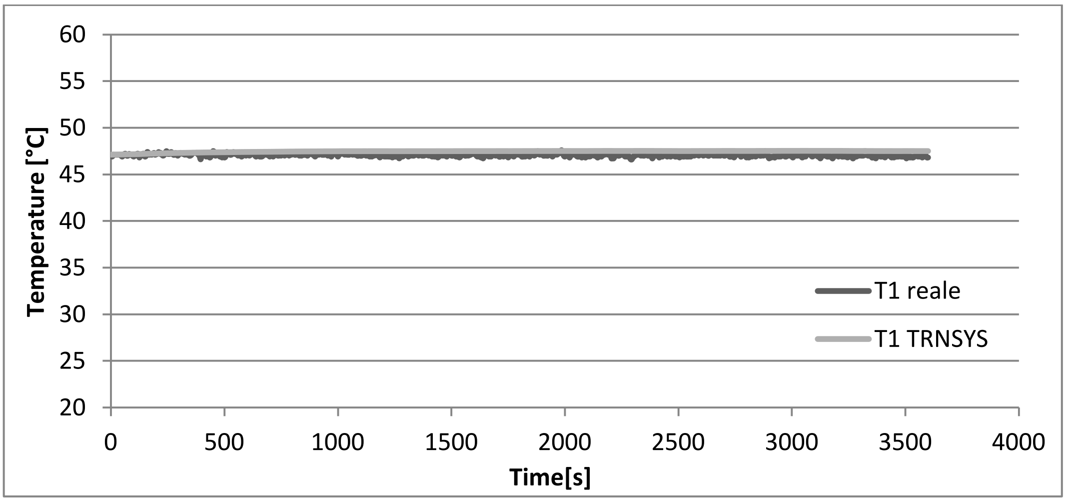


Figure 79. T1 temperatures comparison for the Test 6

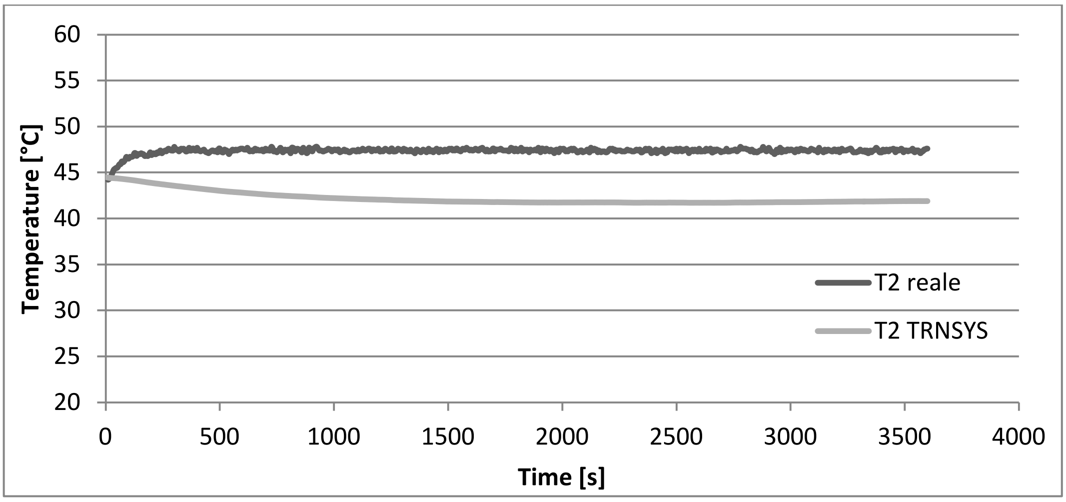


Figure 80. T2 temperatures comparison for the Test 6

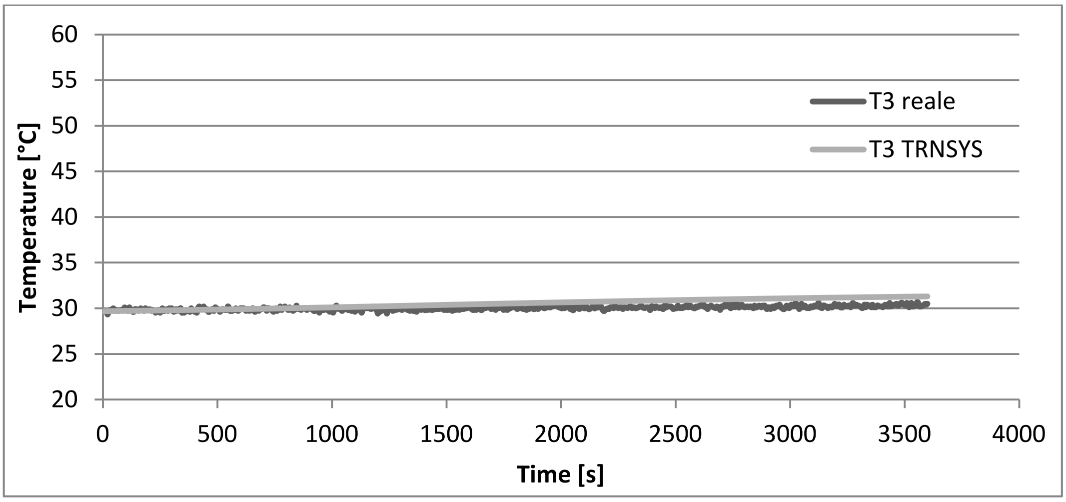


Figure 81. T3 temperatures comparison for the Test 6

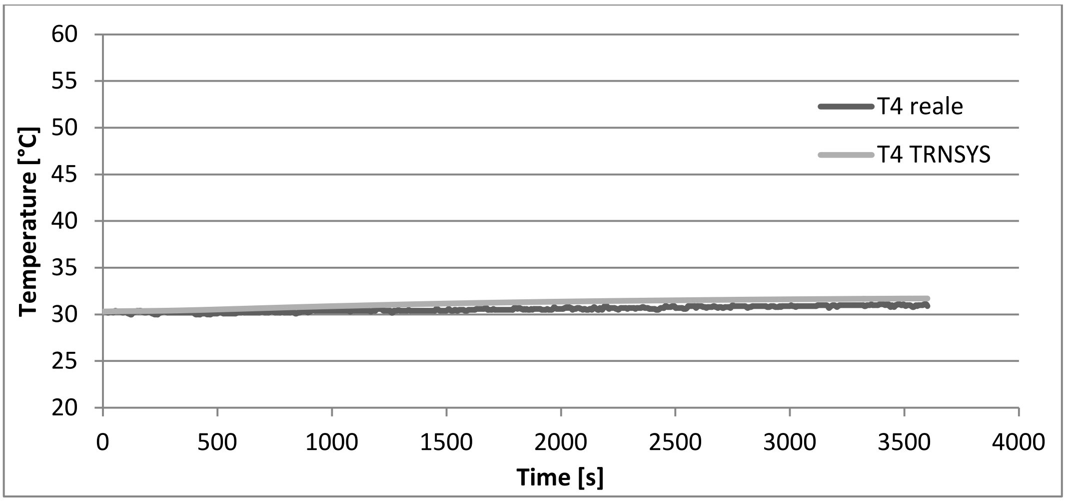


Figure 82. T4 temperatures comparison for the Test 6

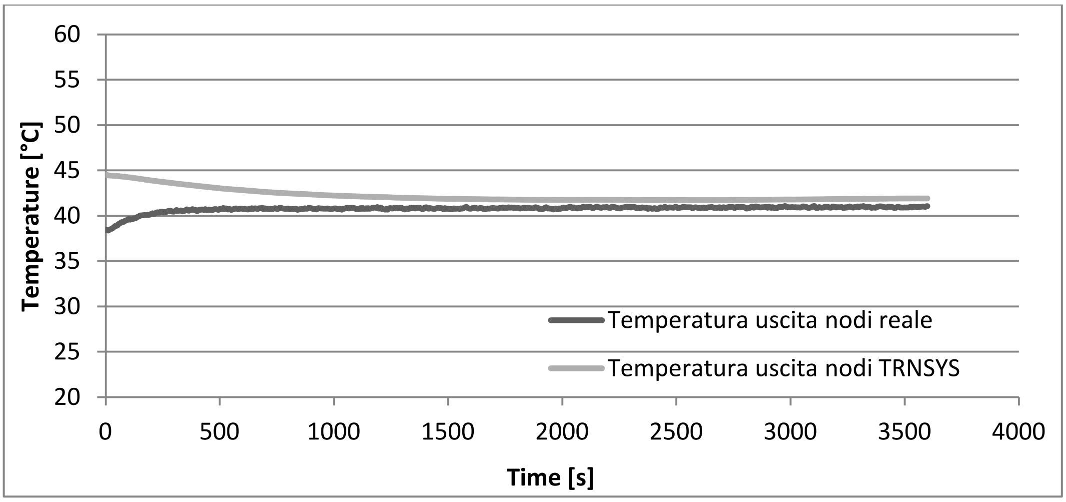


Figure 83. Outlet temperature comparison Test 6

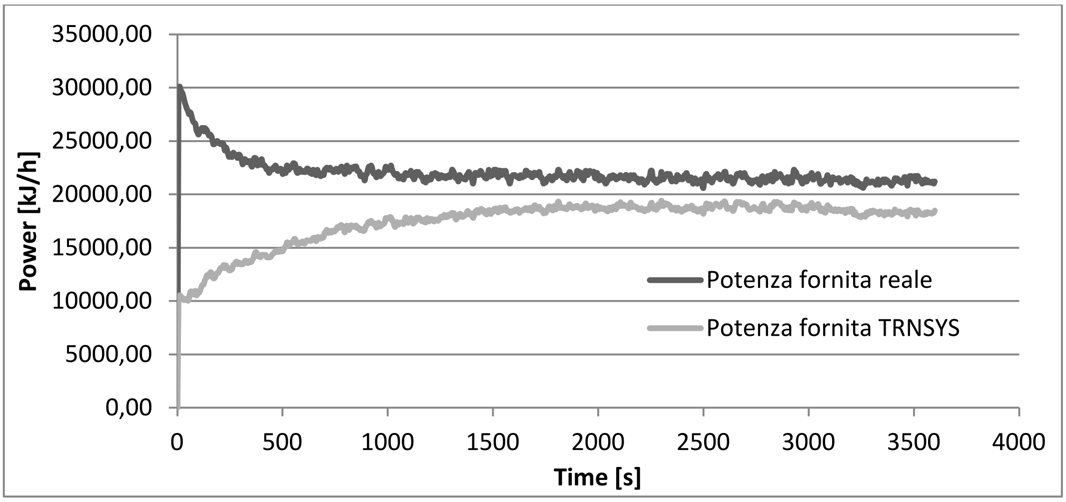


Figure 84. Power comparison Test 6

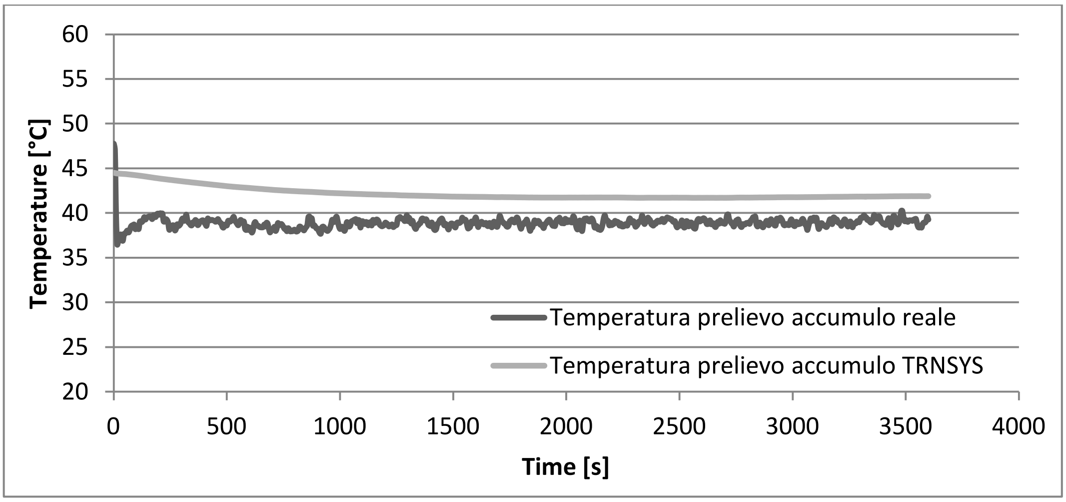


Figure 85. Withdrawal temperatures comparison Test 6

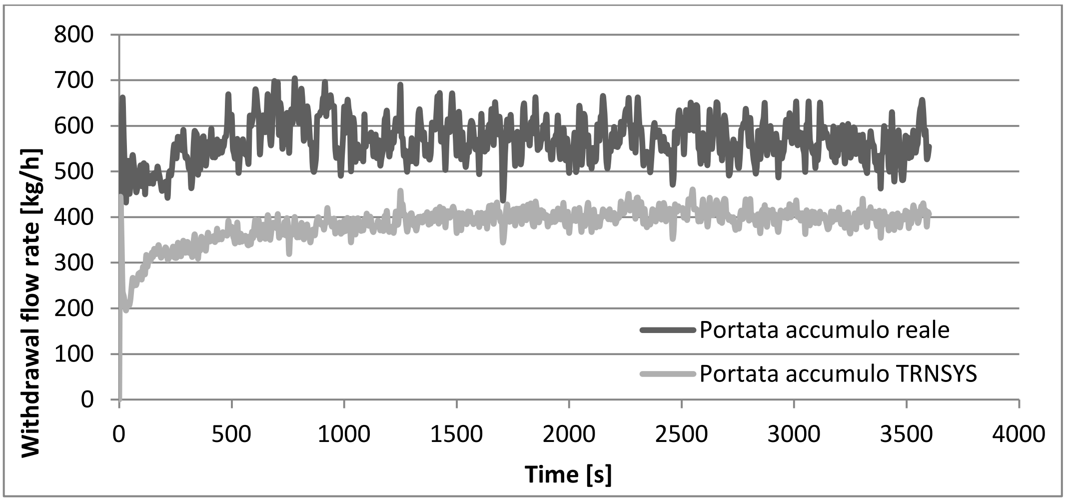


Figure 86. Withdrawal flow rate comparison Test 6

In this test, no longer exists the bypass previously described. This is clearly shown in Figure 80 where the temperature at the node 2 results to be higher than in the previous case, reflecting the fact that the incoming hot water flow has undergone to a change in direction heading towards the lower layers because it has been recalled by the two withdrawals. The temperature difference, between the real case and the simulated one, at the node 2 remains as in the previous case and this is hypothesized to be due to the same reasons already discussed .

Despite the temperature at the second node is high and equal to 47.5 ° C the temperature in the return to the boiler is significantly lower and equal to 41 ° C. This is probably due to the presence of the baffle which, being inclined downwards, draws fluid from the lower layers at a lower temperature. This temperature being lower than the simulated one determines a greater power generated by the boiler due to a higher temperature difference of the flow rate . Again, because of the presence of the deflector, the simulation evaluated a lower temperature for the water extracted to feed the radiant plant respect to the value recorded by the probe.

A.3. The test on the thermal storage 2S 750

For the DHW storage tank 750 2S some tests very similar to the previous ones have been conducted. The difference respect to the previous storage consist in the fact that this tank allowed heat exchanges only through the use of coils, being the tank dedicated to the production of domestic hot water. The temperature sensors are arranged in a different way, there are only two attacks (not four as in the previous tank) and it is thus possible to know the state of the thermal mass of water contained in the accumulation only at two heights, and this makes the tests less detailed and more difficult to implement in the simulation software.

A.3.1 *Test 1: Heating through the solar coil heat exchanger*

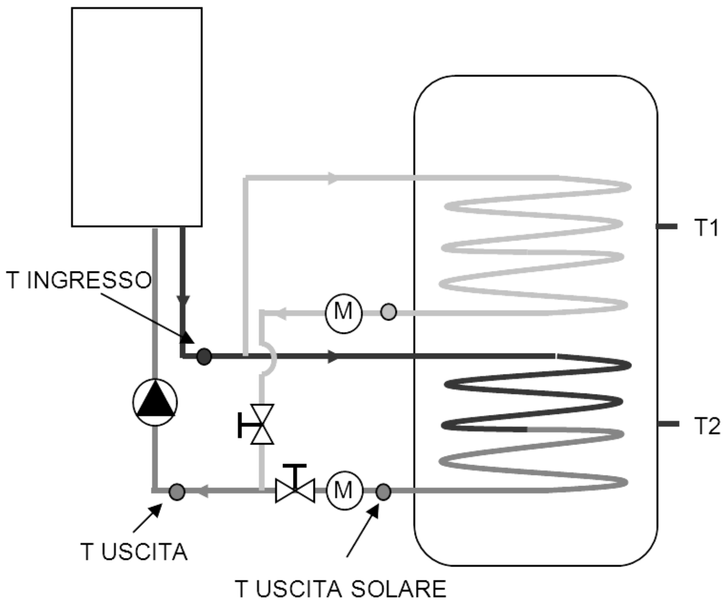


Figure 87. Test 1 facilities

As shown in Figure 87 and as mentioned earlier in this storage tank in this test only two temperature values for the stored water (T1, T2) are available, despite that the measuring points are increased as a thermometer in the proximity of solar output coil (T solar output) was placed.

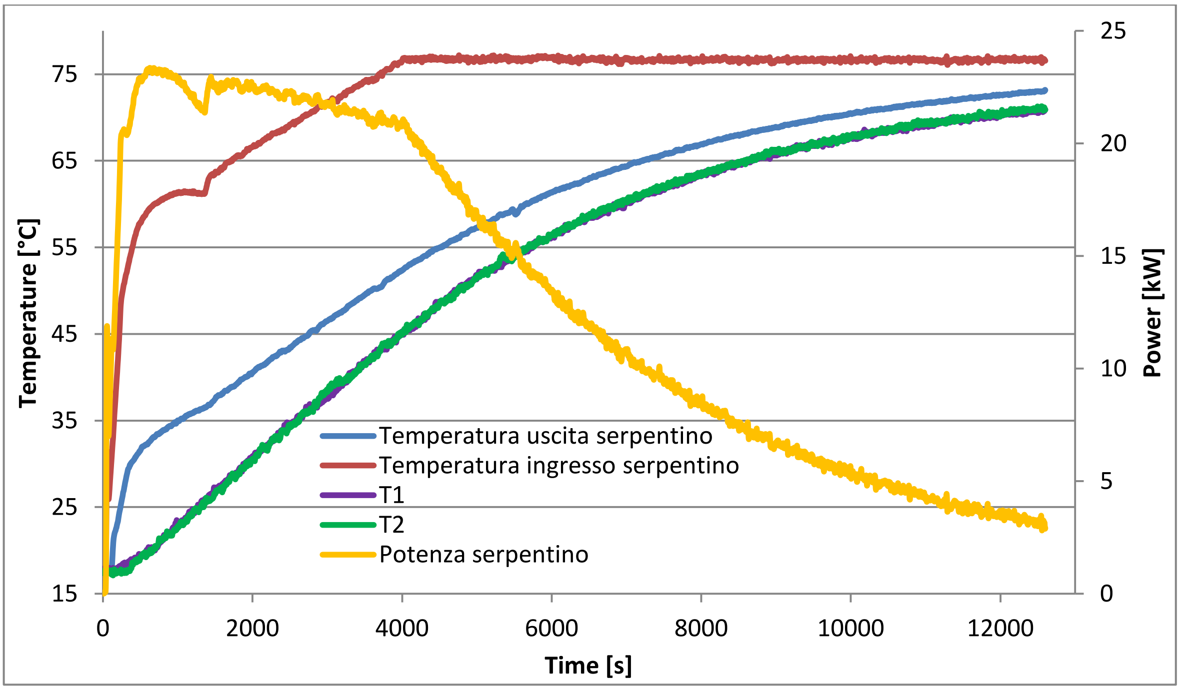


Figure 88. Results of the Test 1

Initial conditions and results of the test are provided in Table 178.

Table 178. Initial conditions and references for the Test 1

Item	Value
T1 initial	17,6°C
T2 initial	17,6°C
Average ambient temperature	20,1°C
Boiler temperature set point	80°C
Average flow boiler	750 l/h
Duration of test	3,5 h
Range data acquisition	5 sec

Table 179. Technical features of the coiled heat exchangers of the tank 2S 750

Item	Value
Outside diameter	0,0318 m
Inner diameter	0,0288 m
Thermal conductivity	200 kJ/h m K
Tube length	25 m
Dimetro spiral	0,590 m
Pitch spiral	0,05 m

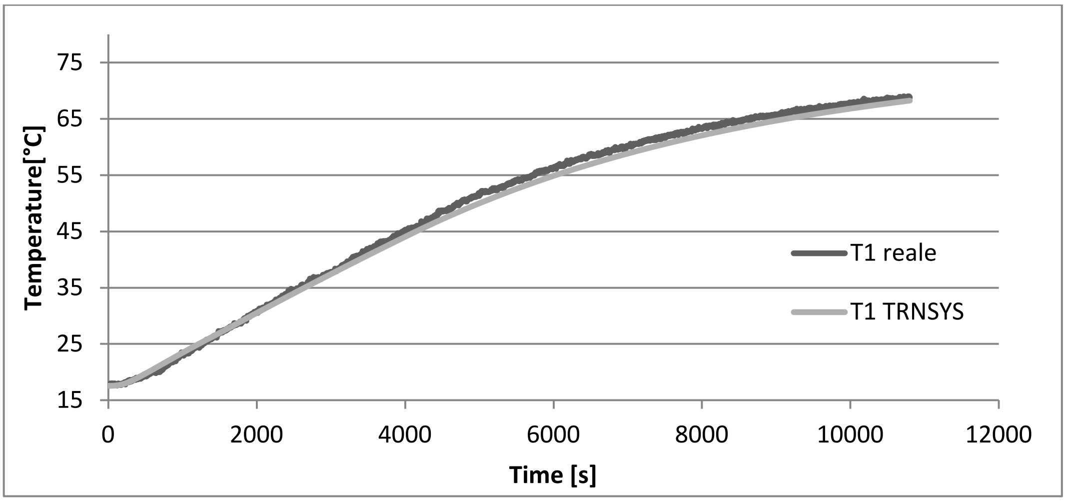


Figure 89. T1 temperatures comparison Test 1

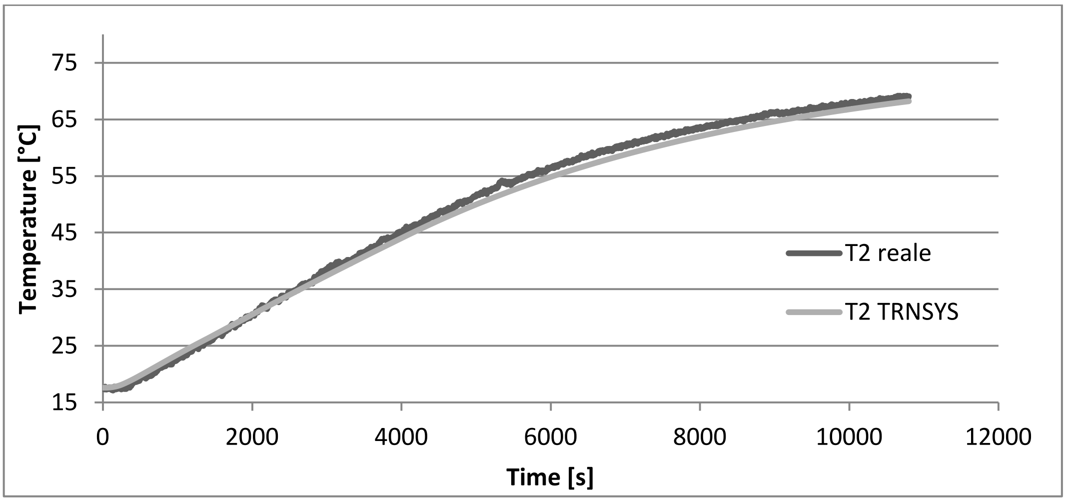


Figure 90. T2 temperatures comparison Test 1

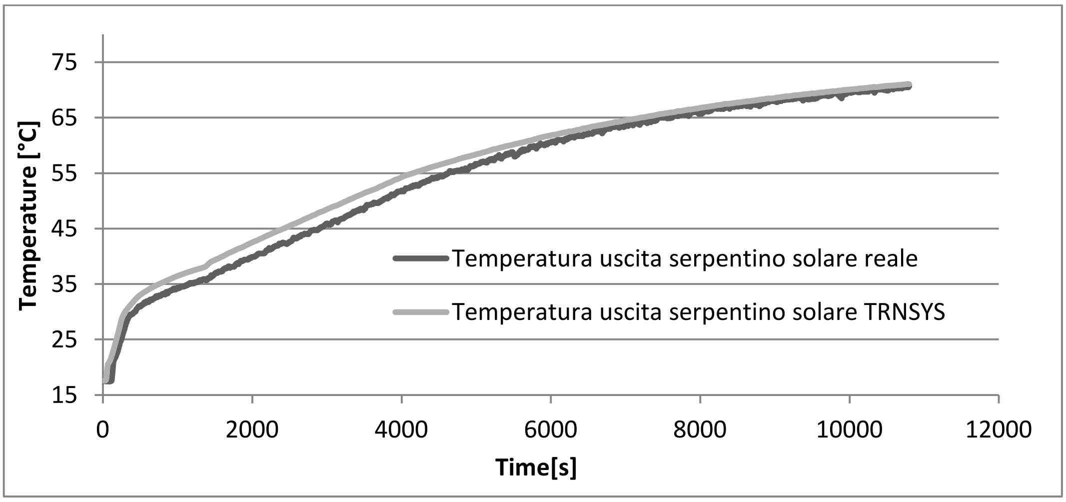


Figure 91. Solar heat exchanger outlet temperature comparison Test 1

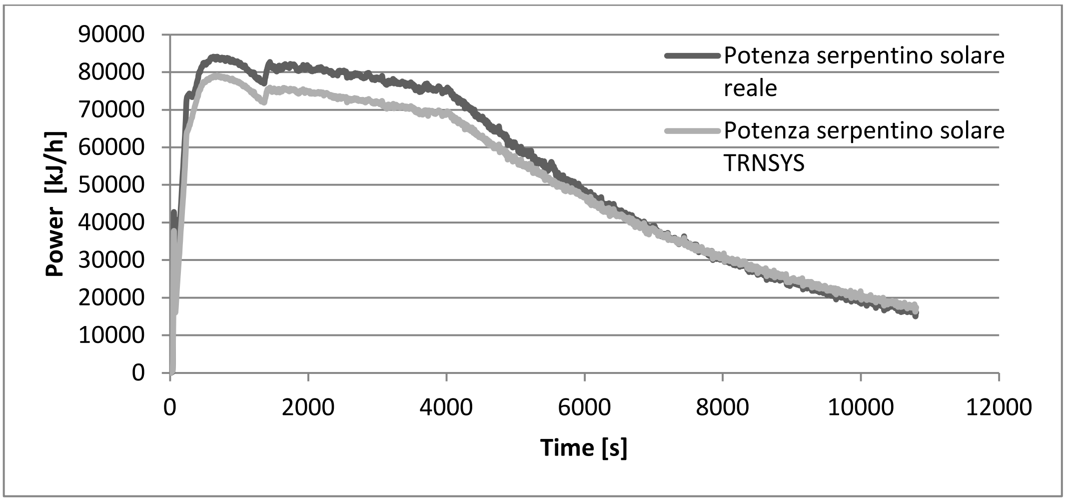


Figure 92. Solar heat exchanger power comparison Test 1

From the graphs it can be seen that the simulation approximates quite well the operation of the real storage. The main difference consists in a lower exchanged power in the virtual case respect to the real one. This means that the software, modeled according to the described features, tends to underestimate the heat exchange, thing that is clear in the graph of Figure 92, in which the power exchanged by the coil is lower especially in the first part of the test, or in the Figure 93 that shows how the overall heat transfer coefficient of the heat exchange results to be lower respect to the real device.

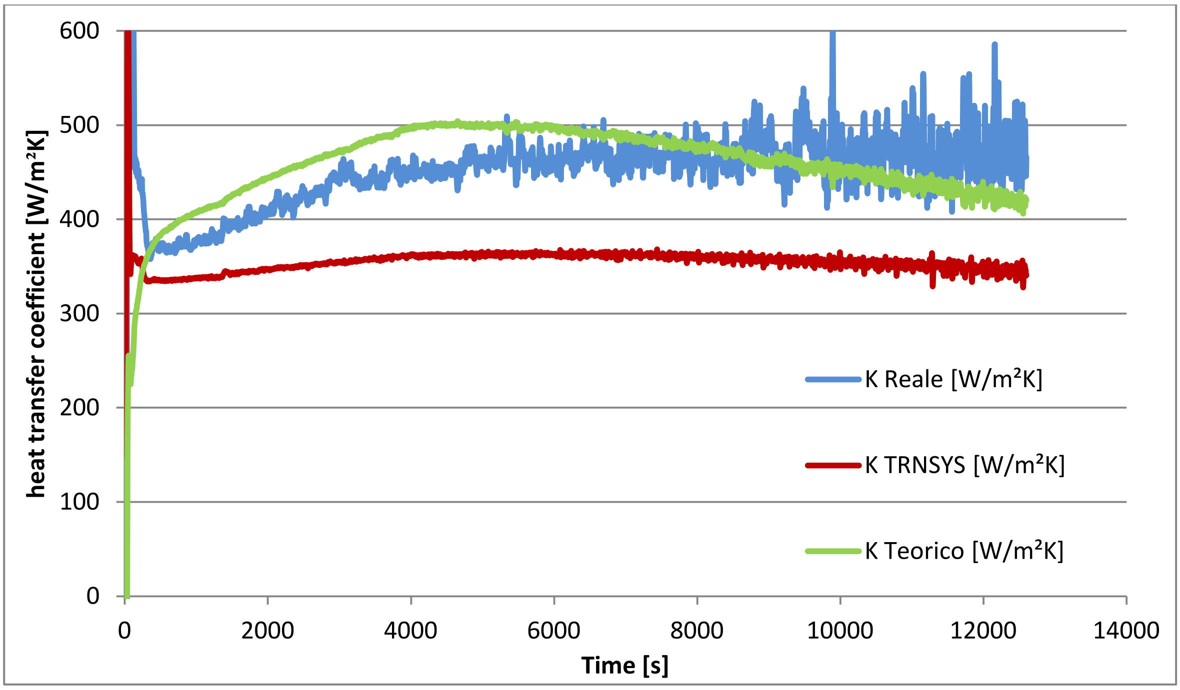


Figure 93. Heat transfer coefficient, K, comparison test 1

The heat transfer coefficient has been evacuate according to the same procedure used for the previous storage. In that case, however the simulation tended to over esteemed the heat exchange, while in this case happened the opposite. With the aim of improving the performance of the simulation and reduce the differences with the measured behavior the calibration of the model was carried out by changing initial conditions to obtain the response represented in the following figures.

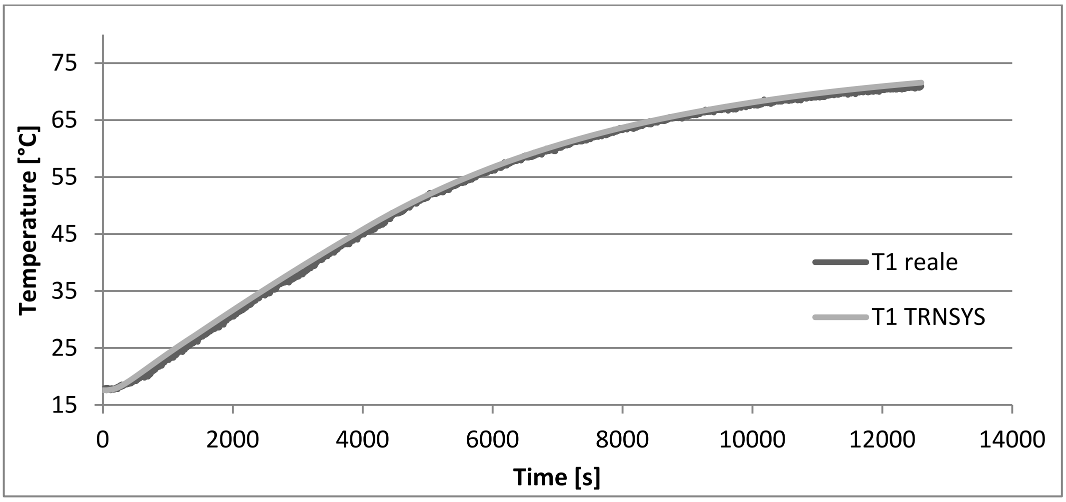


Figure 94. T1 temperatures comparison after the calibration of the Test 11

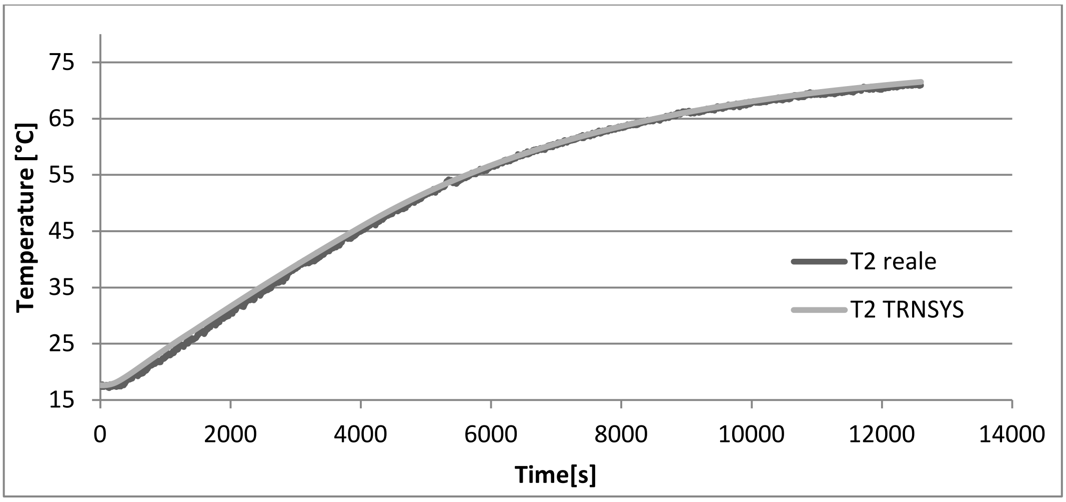


Figure 95. T2 temperatures comparison after the calibration of the Test 1

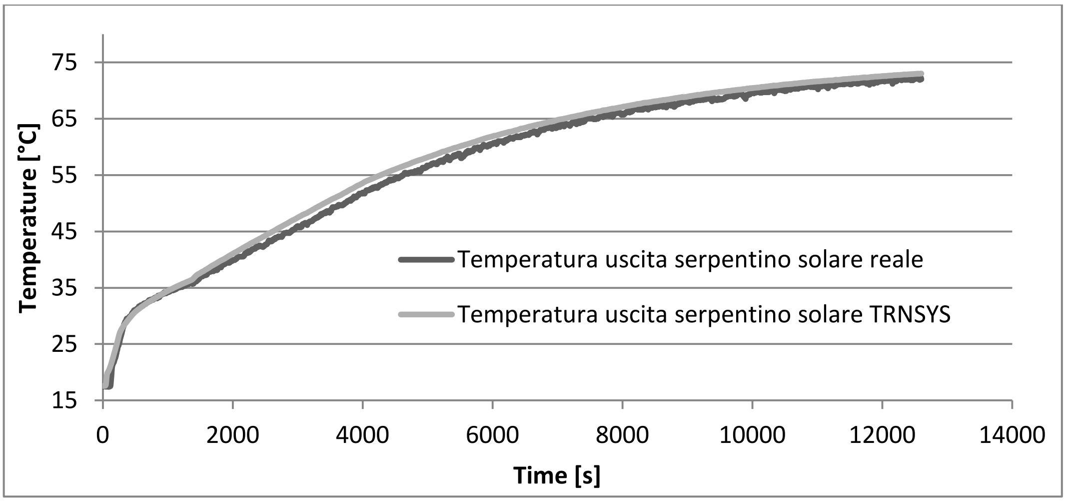


Figure 96. Solar heat exchanger outlet temperatures comparison after the calibration of the Test 1

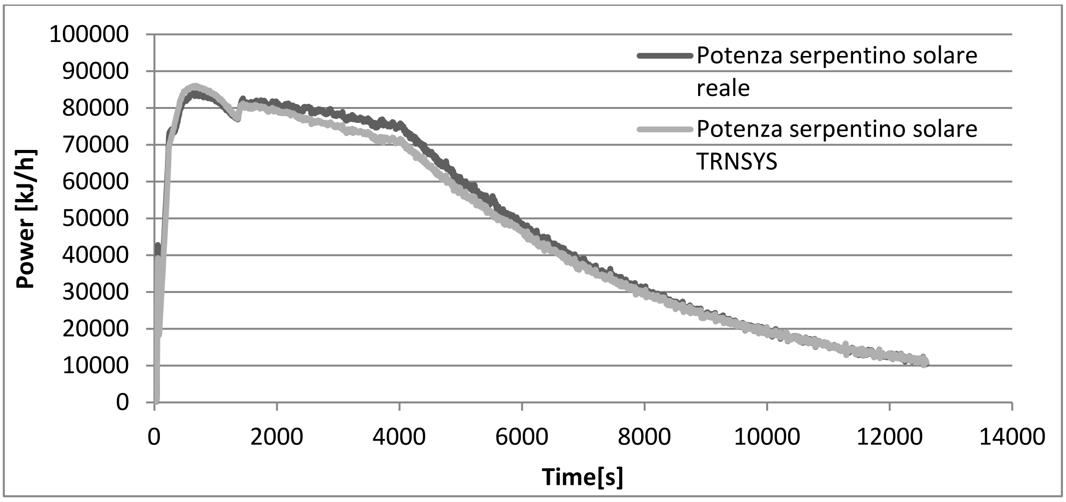


Figure 97. Solar heat exchanger power comparison after the calibration of the Test 1

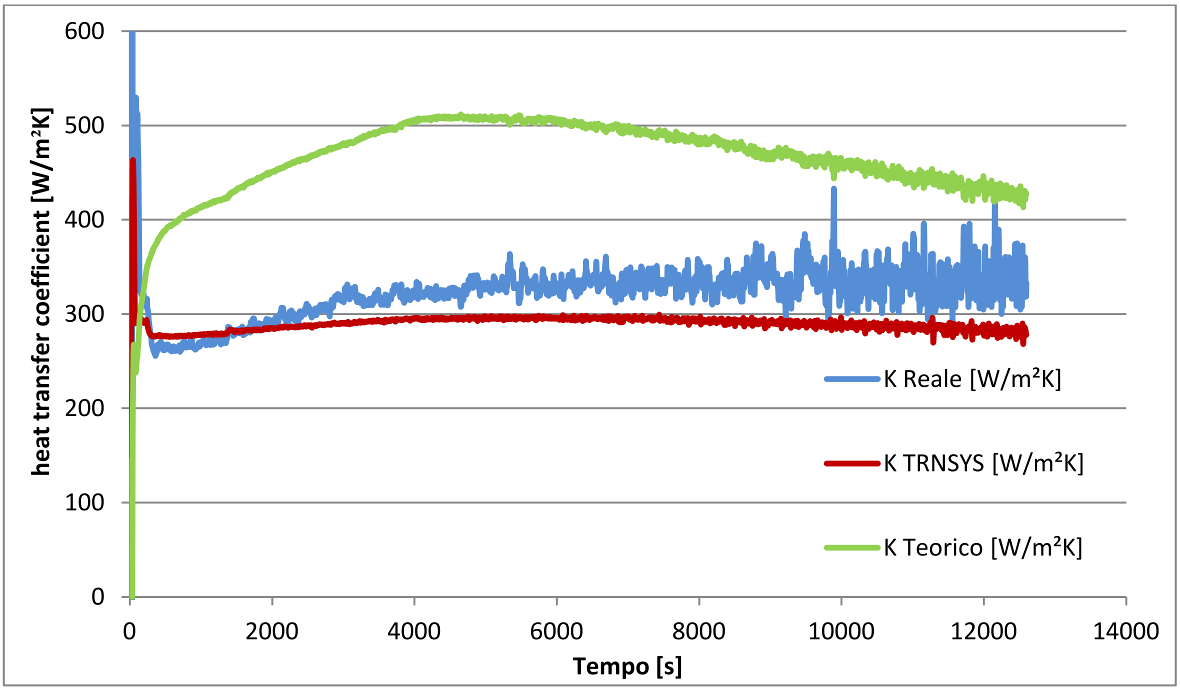


Figure 98. heat transfer coefficient K, comparison after the calibration of the Test 1

To correct the underestimation of heat exchange and obtain more correct value the length of the coil has been increased of 40% (10m) achieving the final value of 35 m. Most likely, the values of the heat exchange surface provided were not entirely accurate and were lower than in reality. In Fact, as it can be deduced from Figure 93 and Figure 98, the differences are significantly reduced, resulting a thermal transmittance value closest to the real one.

A.3.2 *Test 2: Temperature drop test with balanced thermal storage*

After having stabilized the thermal storage at a temperature of 70 °C a test of temperature drop was carried out. During the 12 hours of the test data have been recorded every 20 seconds. Results are shown in Figure 99. The initial conditions are presented in Table 180.

Table 180. Initial conditions and parameters of the Test 2

Item	Value
T1 initial	70,9 °C
T2 initial	70,6 °C
Average ambient temperature	20,9 °C
Duration of test	12 h
Range data acquisition	20 sec

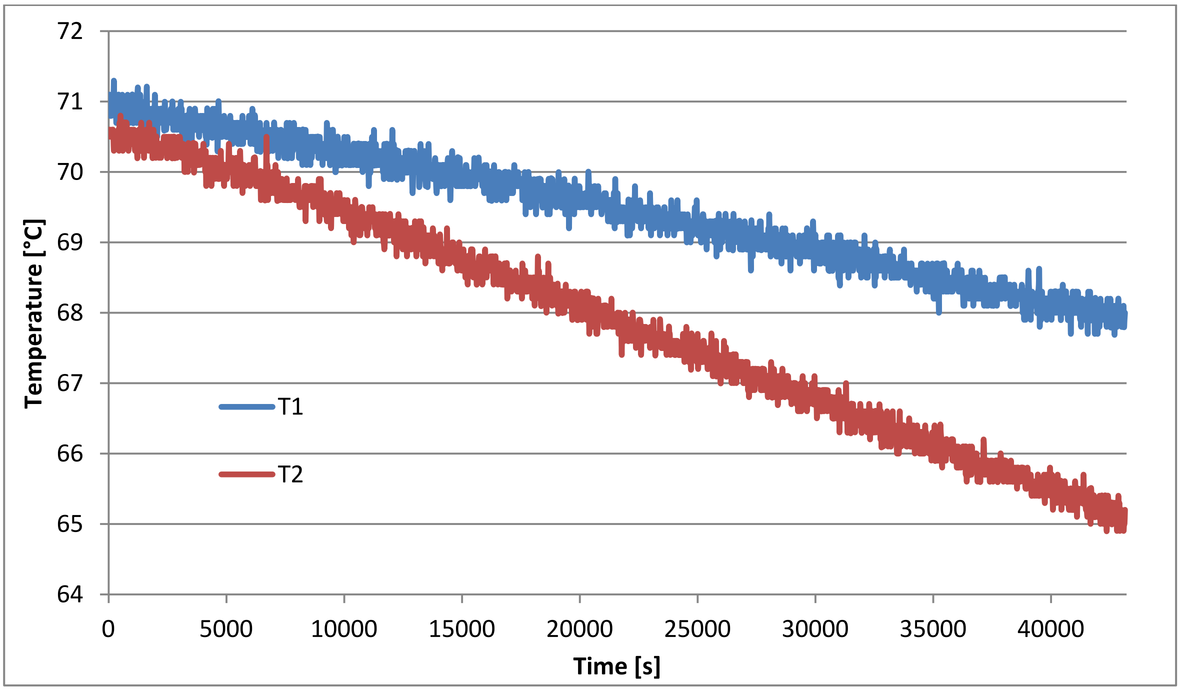


Figure 99. Results of the Test 2

Since the data of the coefficients of thermal dispersion through the external wall of the heating tank have been obtained from the calibration, it was decided to carry out the simulation of the DHW tank on the basis of the same values. As seen previously the exchange coefficient of the insulating layer was calculated and knowing that the conductivity of the rigid polyurethane is equal to 0.028 W/mK is has been obtained a value of 0.40 W/m²K, which is very similar to that of the tank heating.

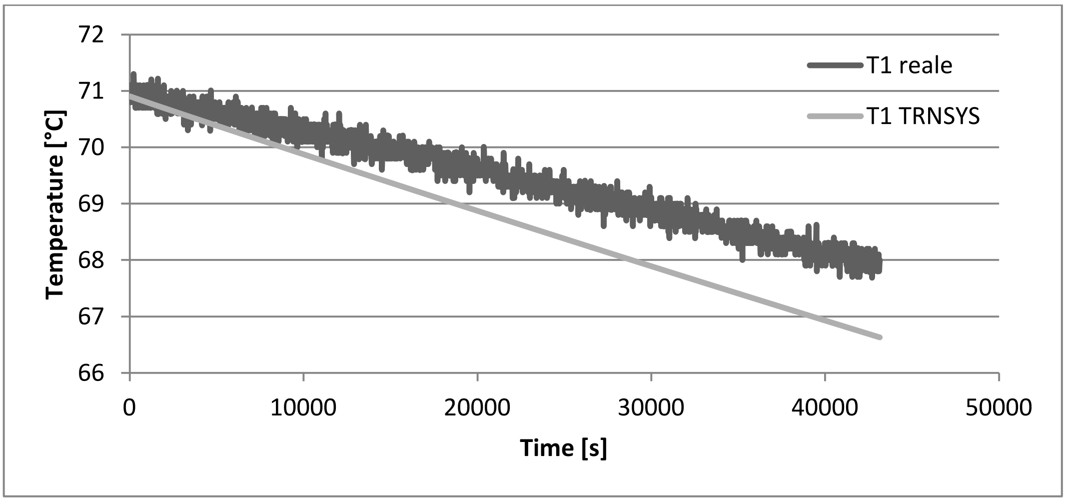


Figure 100. T1 temperatures comparison Test 2

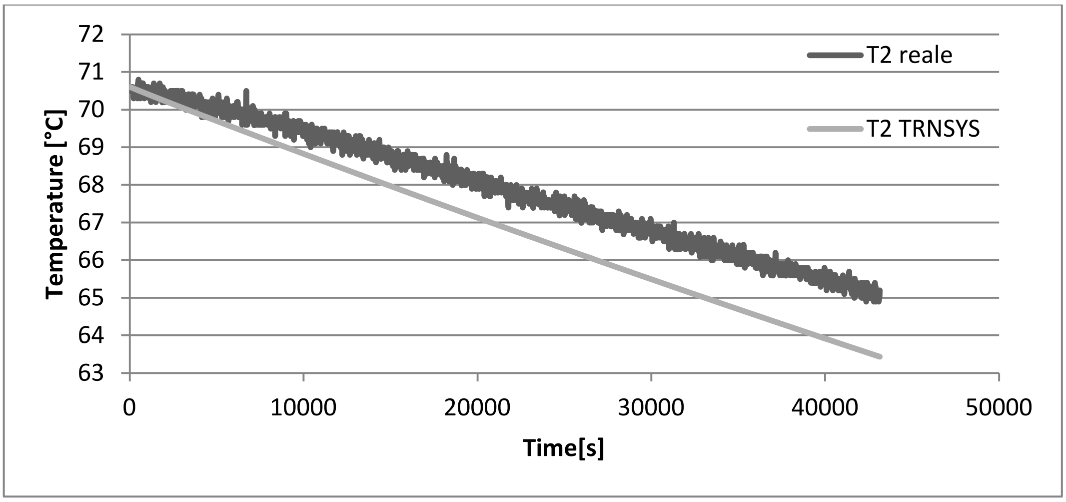


Figure 101. T2 temperatures comparison Test 2

Notwithstanding the foregoing, the results show a too high thermal dispersion in the simulated case, and this means that the initial values of the loss coefficients are too low and that most likely the type of insulation used in reality it is more efficient than estimated. To calibrate the model were reduced initial loss coefficients according to the values contained in Table 181, the results presented subsequently have been obtained, results which can be considered fully acceptable.

Table 181. Heat losses coefficient after the calibration

Item	Value
Top heat losses coefficient	3 kJ/h m² K
Edge heat losses coefficient	3 kJ/h m² K
Bottom heat losses coefficient	21 kJ/h m² K

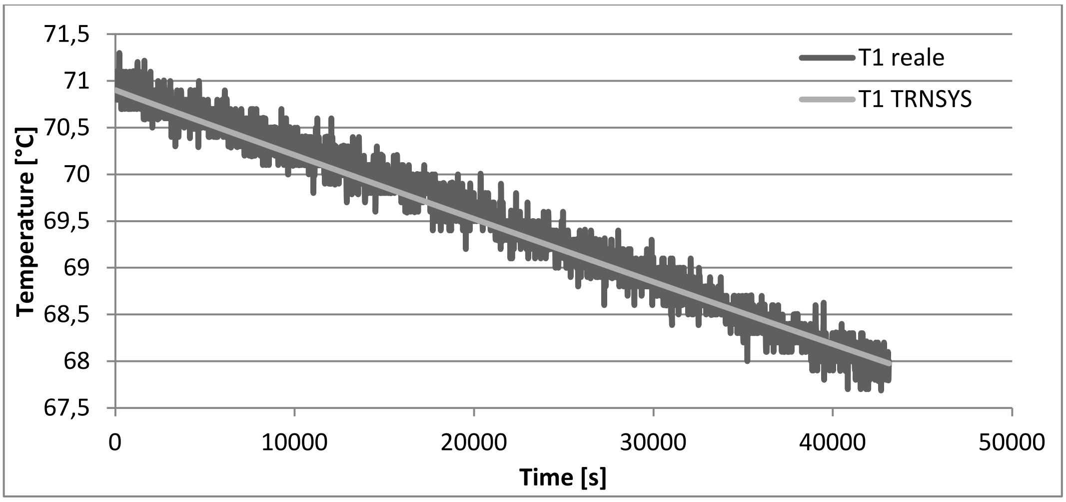


Figure 102. T1 temperatures comparison after the calibration of the Test 2

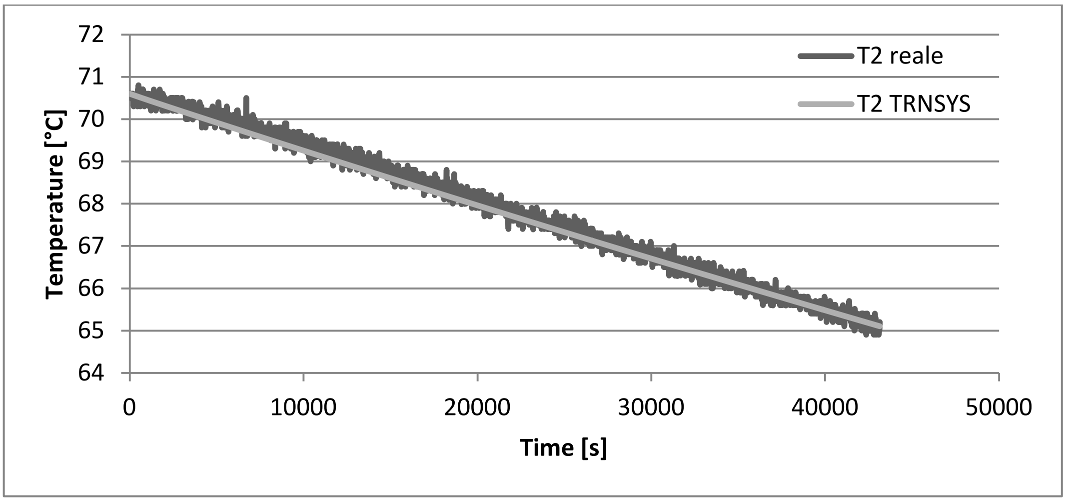


Figure 103. T2 temperatures comparison after the calibration of the Test 2

A.3.3 *Test 3: Heating Test by the means of the boiler coiled heat exchanger*

The test is similar to the correspondent one carried out for the tank dedicated to the heating, but in this case, the water flow from the boiler cannot be delivered directly in the inner volume, but flows through the coiled heat exchanger.

Table 182. Initial conditions and parameters for the Test 3

Item	Value
T1 initial	16,6 °C
T2 initial	16,3 °C
Average ambient temperature	20,5 °C
Boiler temperature set point	50 °C
Average flow boiler	750 l/h
Duration of test	2 h
Range data acquisition	5 sec

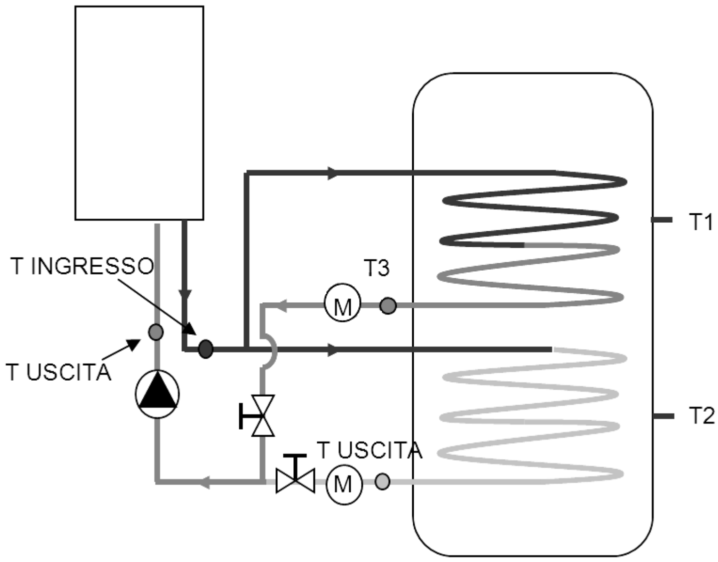


Figure 104. Test 3 facilities

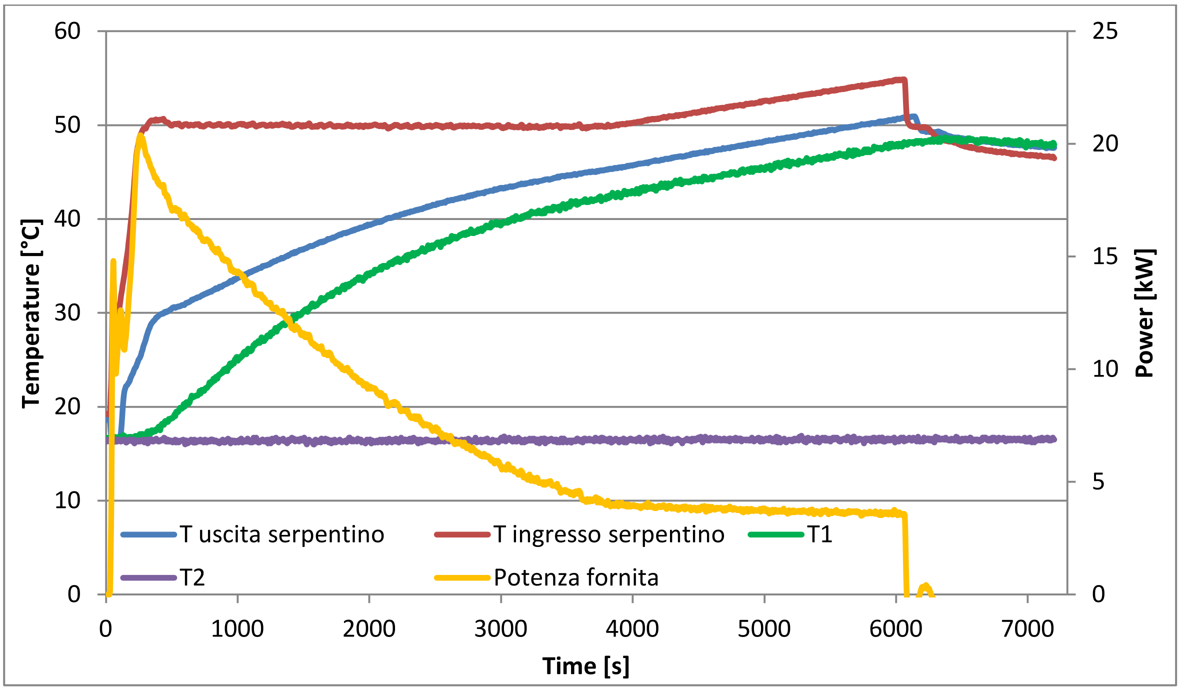


Figure 105. Test 3 results

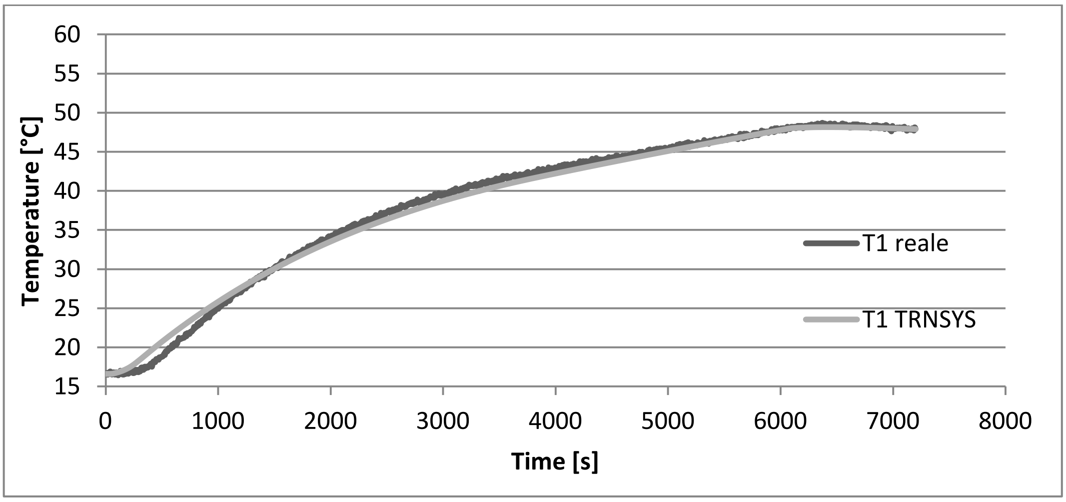


Figure 106. T1 temperature comparison Test 3

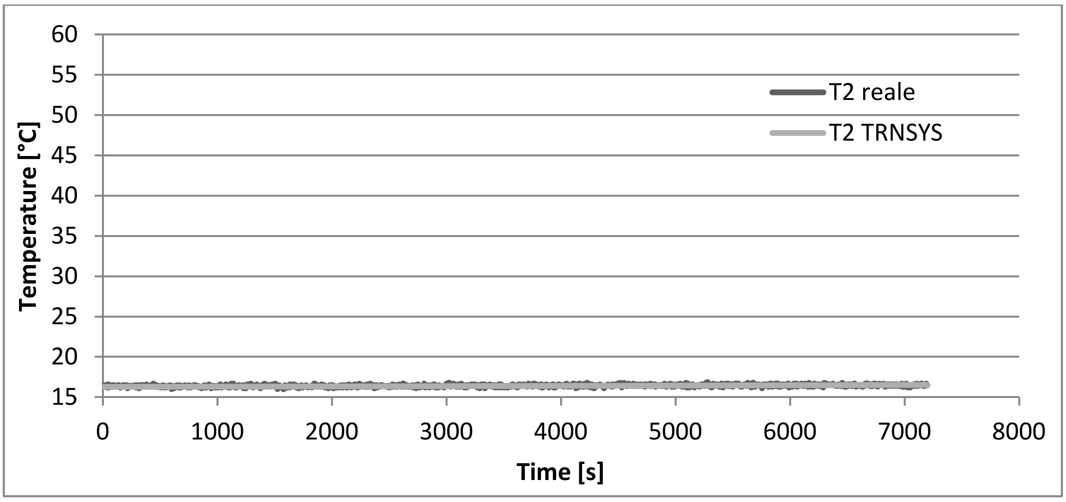


Figure 107. T2 temperature comparison test 3

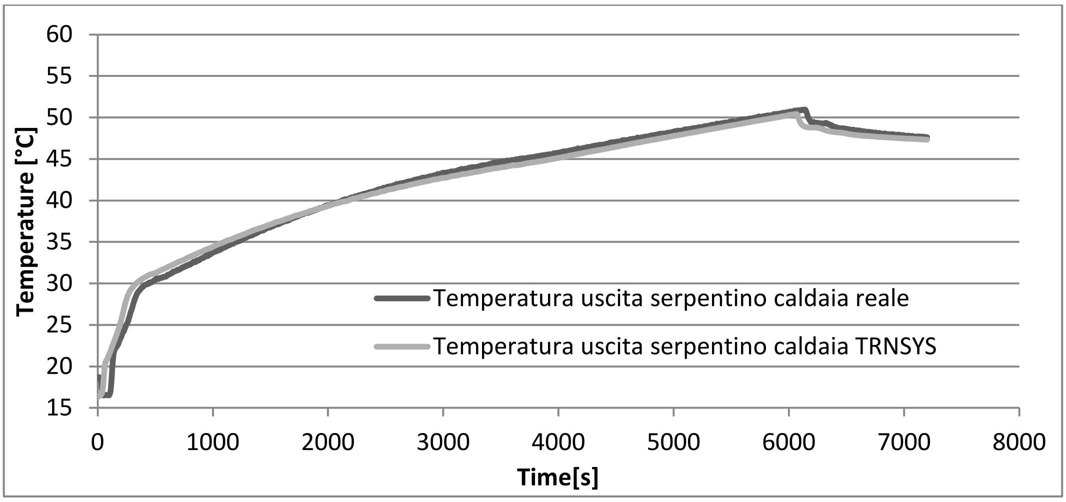


Figure 108. Outlet temperature comparison of the boiler coil test 3

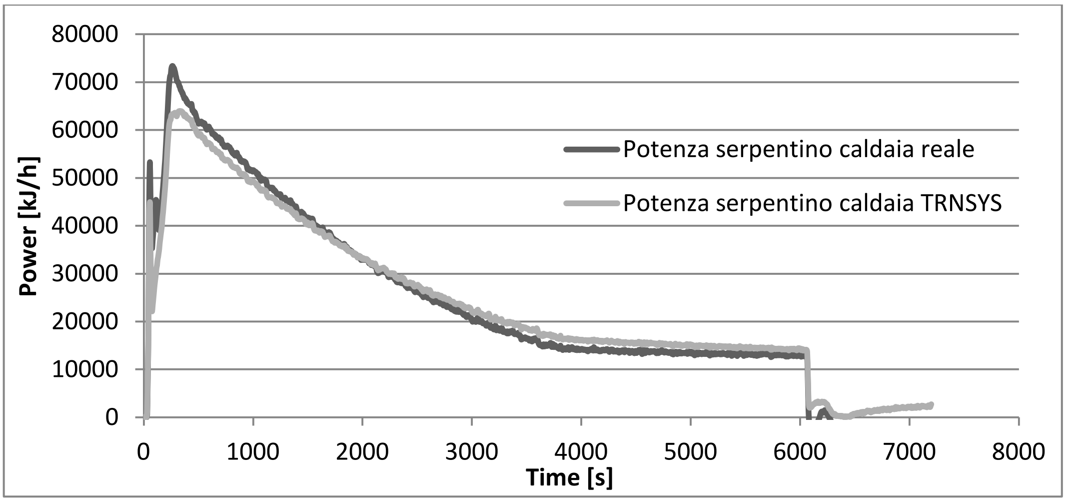


Figure 109. Power comparison of the boiler coil Test 3.

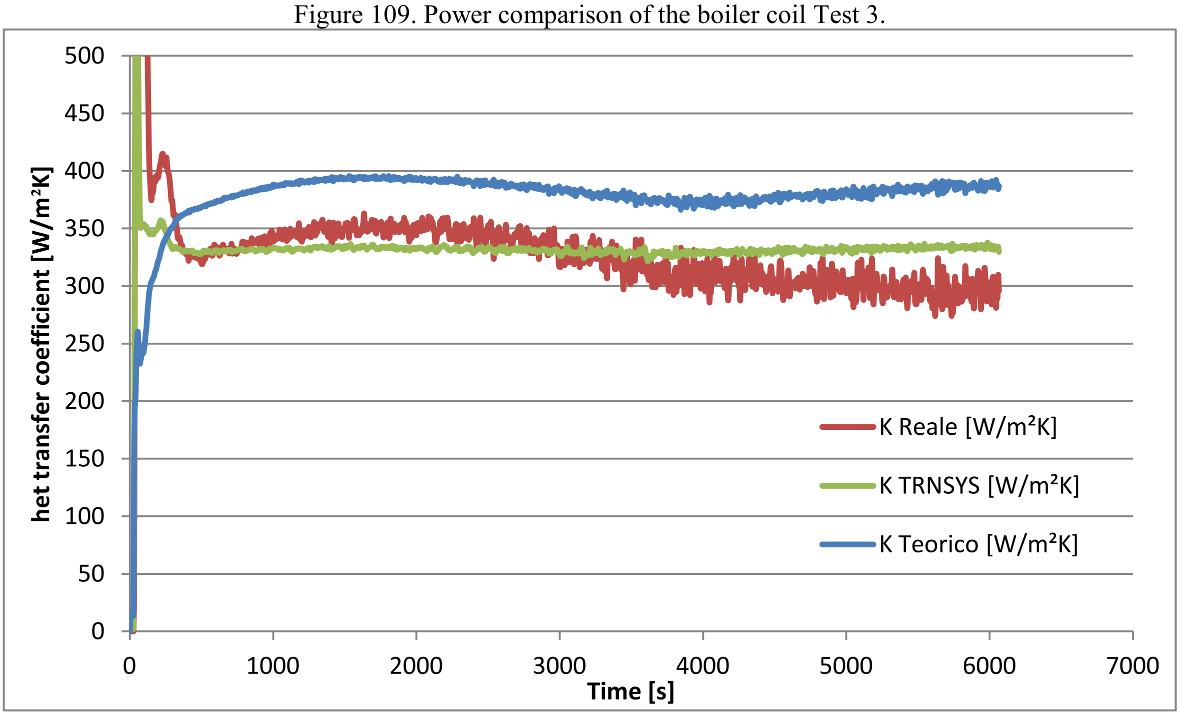


Figure 110. Heat exchange coefficient comparison Test 3

The differences between real and the simulated value are minimal and, as showed in Figure 110, the overall heat transfer coefficient realize a good correspondence. Despite that a calibration was still performed in order to enhance the difference between the exchanged power values that occurs in the first part of the simulation. To achieve the calibration of the model the length of the top coil has been changed by attempts. The obtained results are showed in Figure 111 to Figure 115.

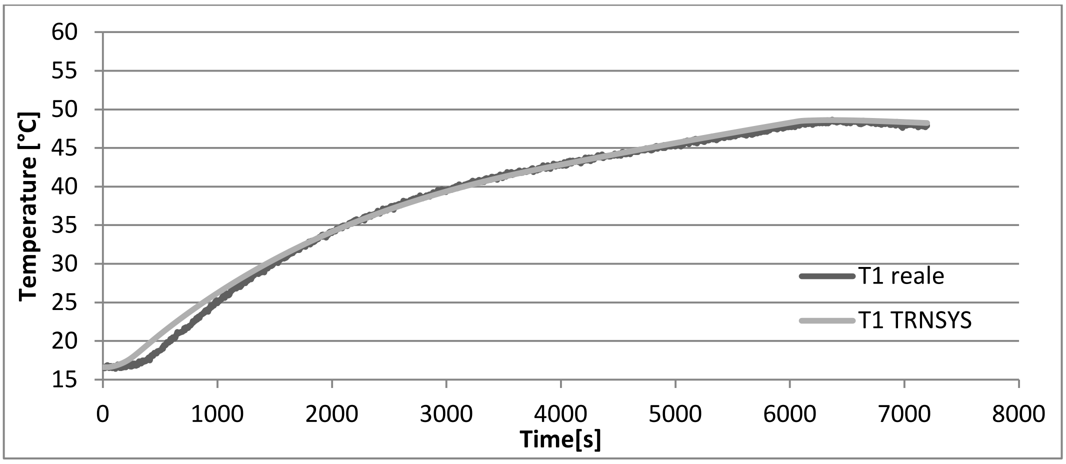


Figure 111. T1 temperature comparison after the calibration of the test 3

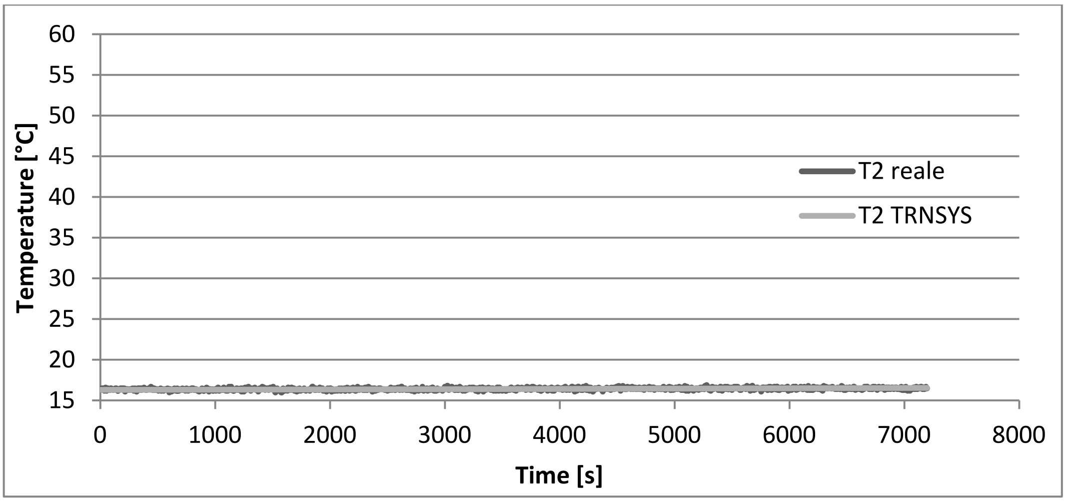


Figure 112. T2 temperature comparison after the calibration of the test 3

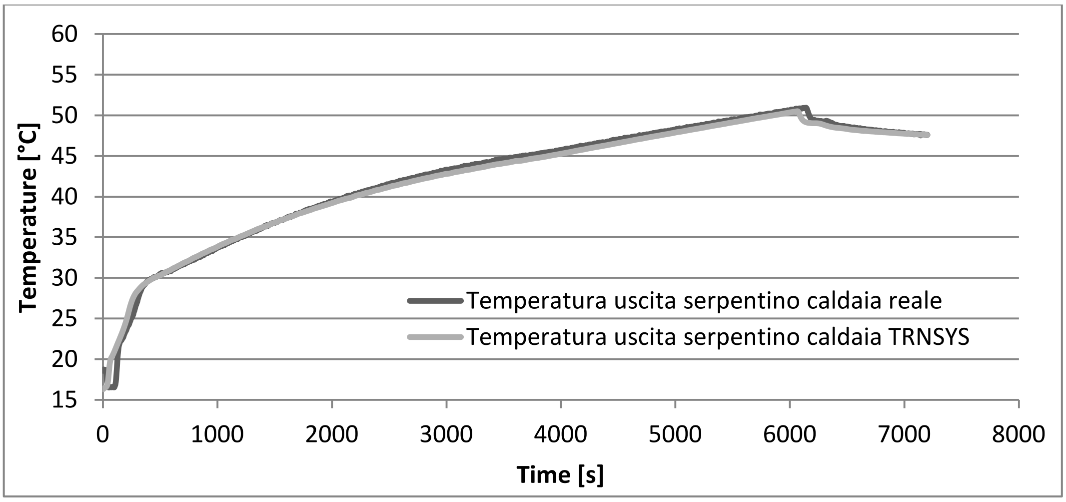


Figure 113. Outlet temperature of the boiler coil after the calibration of the test 3

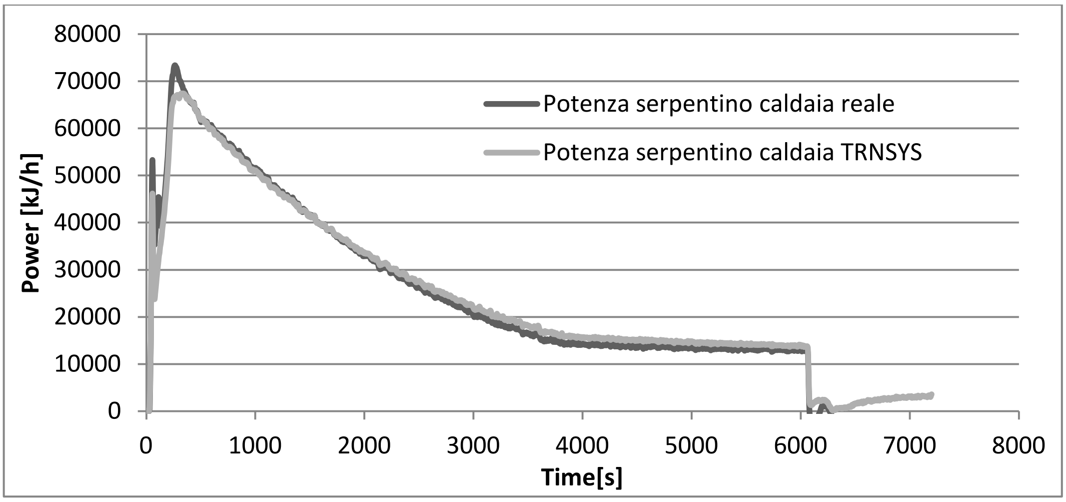


Figure 114. Exchanged power comparison of the boiler coil after the calibration of the Test 3

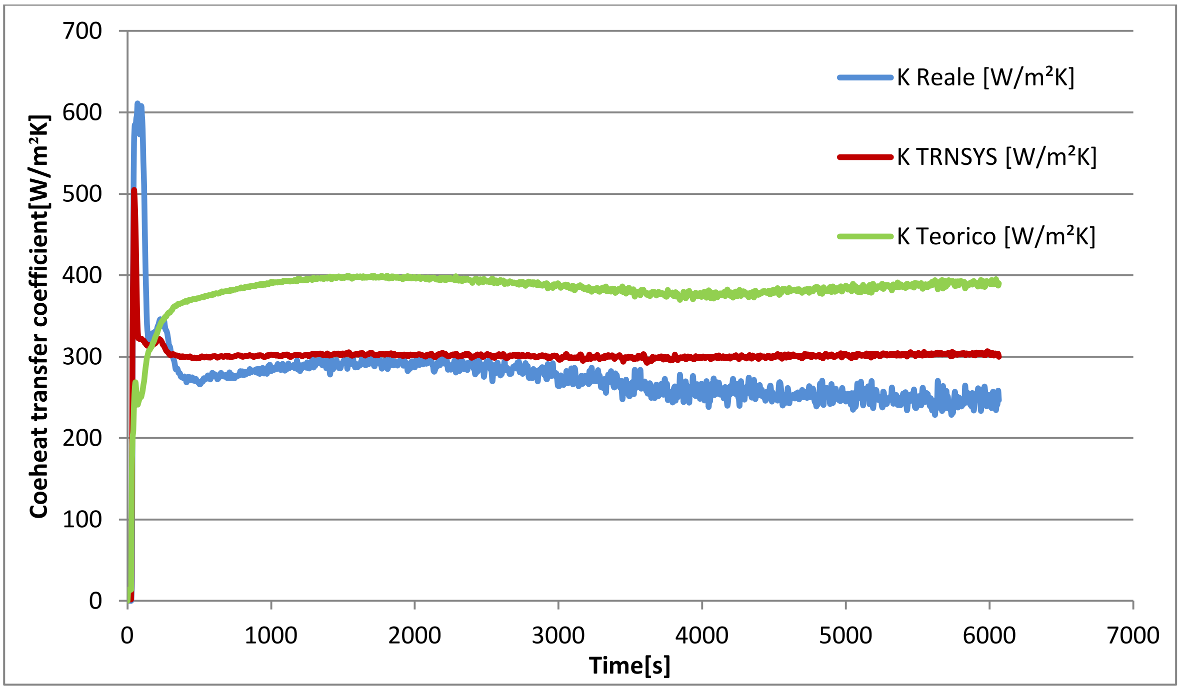


Figure 115. Heat exchange coefficient comparison after the calibration of the Test 3

The results presented in Figure 115 show how it has been possible to reduce the difference between reality and simulation, especially in the first part of the simulation, where the thermal load was grater. Although in the second part of the test remains a small difference that is highlighted by the fact that the simulated heat exchange coefficient does not overlap perfectly to the real one, the differences are, however, of the order of 7000 kJ/h i.e. below 2 kW, and can be considered acceptable. The same thing can be said for the outlet temperature from the coil whose average value is lower than the real case by only 0.3 °C.

A.3.4 *Test 4: Heating Test by the means of the boiler coiled heat exchanger and contemporary s withdrawal of DHW*

The test analyzed the heating of the storage by the means of the upper coil, and the contemporary draw of DHW from the upper junction. Of course a flow arte equal to the drawn one needs to be supplied from at the bottom of the storage, with a cold temperature. The DHW flow is managed to have a fixed temperature of 50°C maintained by the means of a thermostatic valve which operate mixing the outflow from the storage with a cold water flow from the aqueduct. This test is intended to simulate the operation of the storage in winter conditions, when the energy contribution of the solar system is zero.

The results presented in Figure 117 to Figure 123 show that the behavior of the simulated tank is not the desired one, in fact having previously realized the calibration of the coil exchanger a better meeting between the simulation results and the measurements was expected. Analyzing these results, it is evident that the modeled heat exchanger fails to generate a sufficient high heat output compared to the real case. The confirmation is provided by the fact that the temperature of the fluid drawn to the DHW circuit has a lower temperature level respect to the desired one, so a higher flow rate is necessary. On the contrary the flow temperature returning to the boiler present in the simulation an higher value respect to the measurements, index of a lower thermal power exchanged in the coil. The difference in the power supplied by the boiler has been evaluated in 39632 kJ/h i.e. 11 kW.

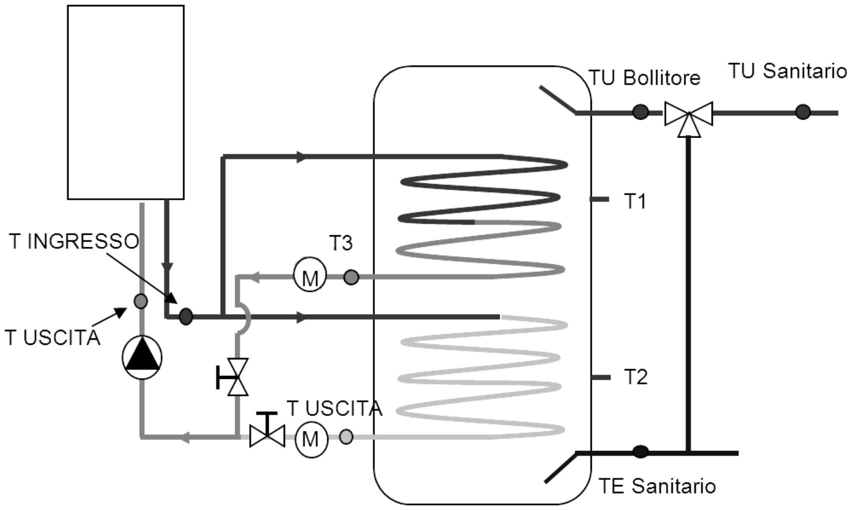


Figure 116. Test 4 facilities

Table 183. Initial conditions and parameters for the Test 4

Item	Value
T1 initial	70,8 °C
T2 initial	58,7 °C
Average ambient temperature	23,6 °C
Boiler temperature set point	80 °C
Average flow boiler	750 l/h
Temperature set point thermostatic valve	50°C
Average DHW flow	1000 l/h
duration of test	69,5 min
Range data acquisition	5 sec

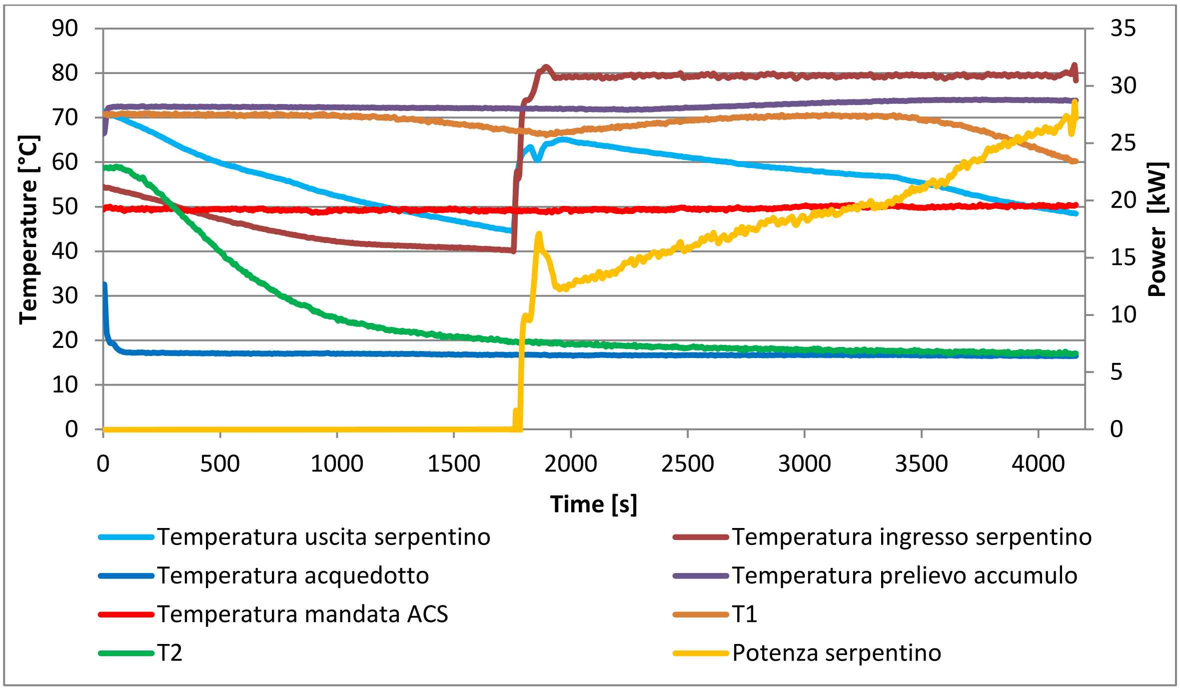


Figure 117. Test 4 results

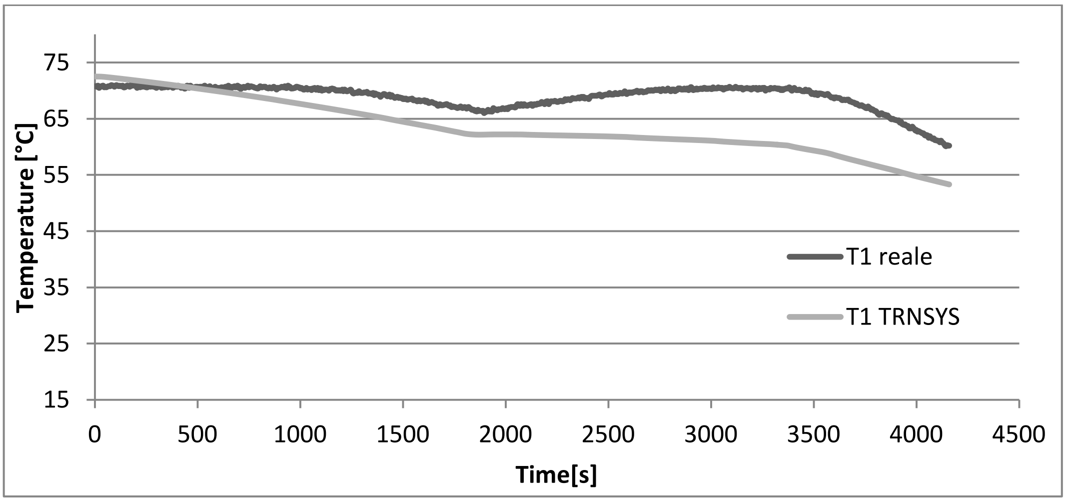


Figure 118. T1 temperature comparison Test 4

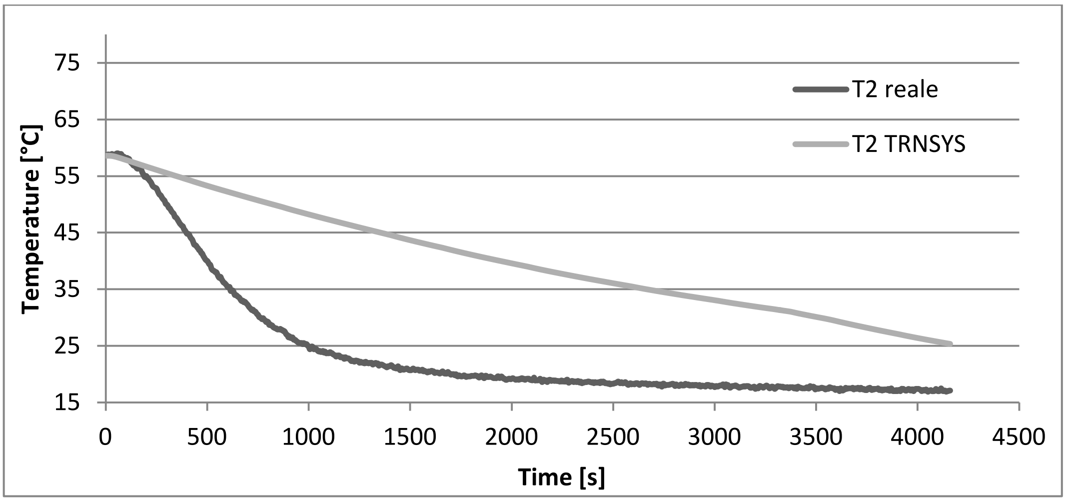


Figure 119. Figura 5.99 T2 temperature comparison Test 4

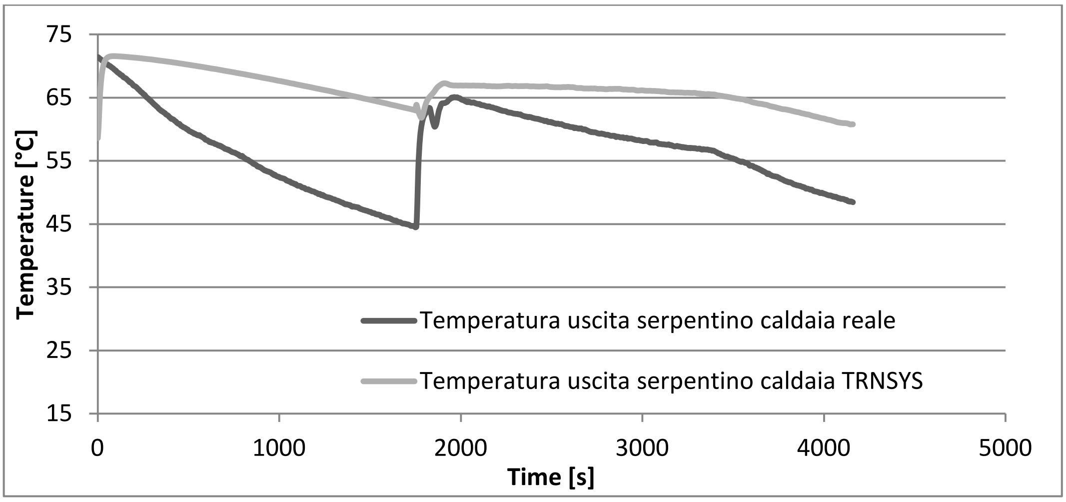


Figure 120. Outlet temperature of the boiler coil after the calibration of the Test 4

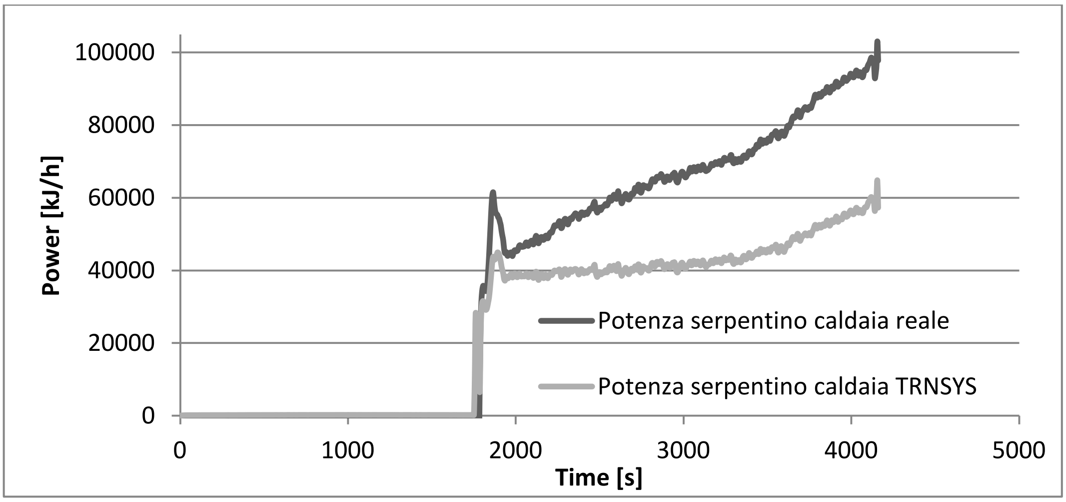


Figure 121. Exchanged power comparison of the boiler coil after the calibration of the Test 4

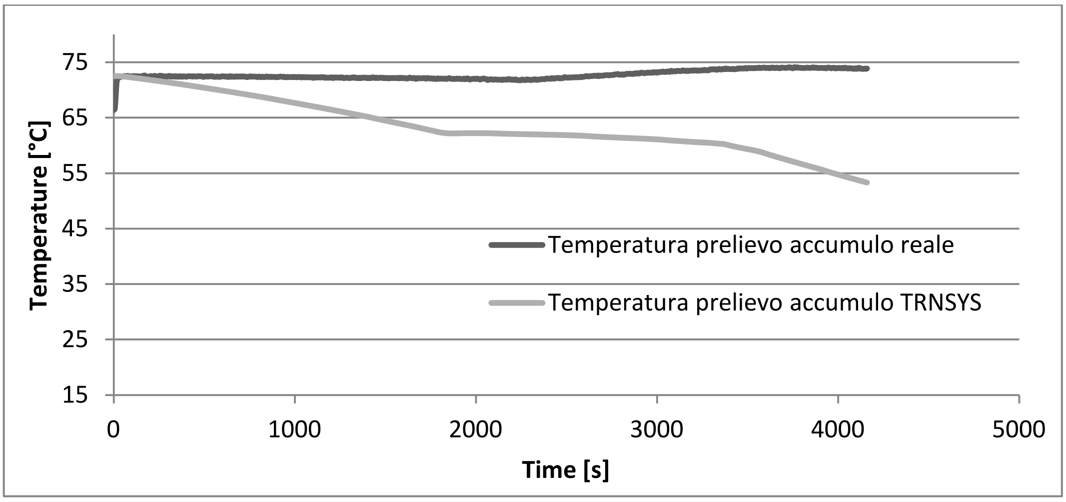


Figure 122. Withdrawal temperature comparison Test 4

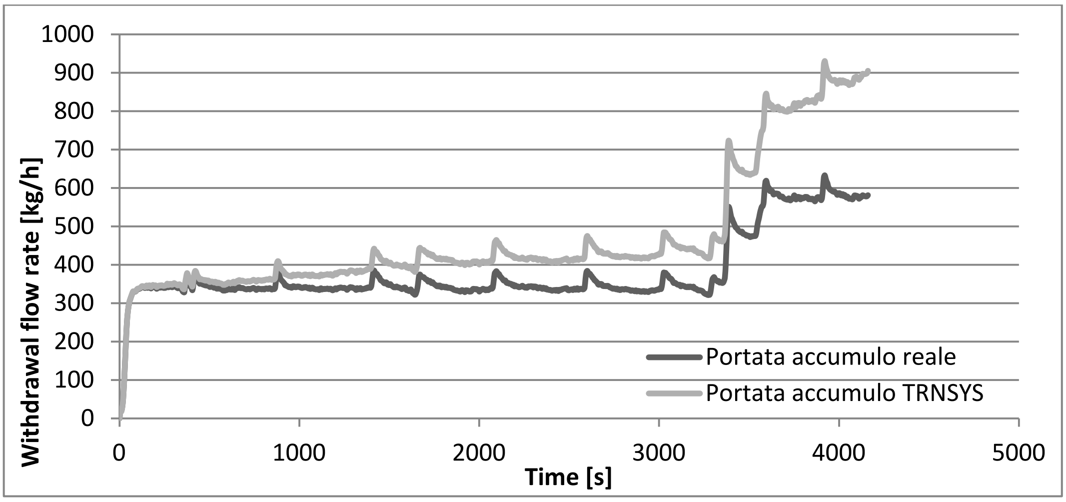


Figure 123. Withdrawal flow rate comparison Test 4

A.3.5 *Test 5: Heating with variable flow rate through the coil of the solar circuit*

The test carried out evaluate the operation of heating the storage by the means of the solar system coil, the involved flow rate has a range between 650l/h and 1200 l/h, during alternate steps of 10 minutes. The purpose was to study how the storage responded to a transient solicitations and to highlight how the flow rate and the fluid temperature affect the heat exchange along the coil.

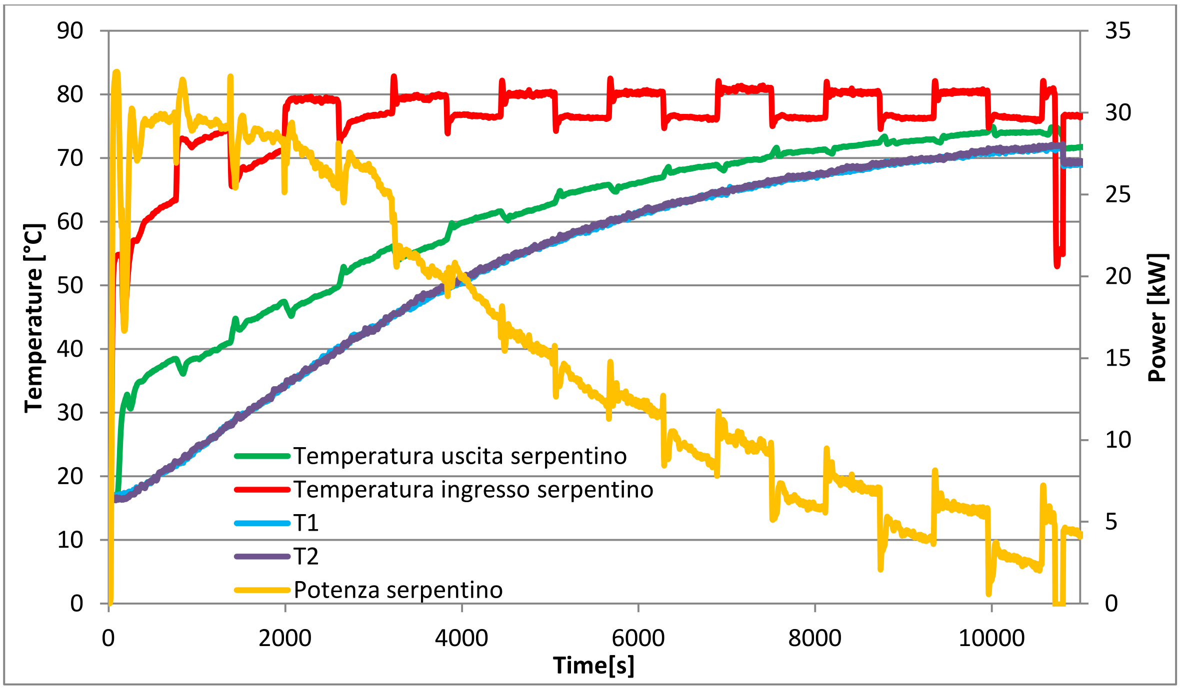


Figure 124. Test 5 results

Table 184. Initial conditions and parameters of the Test 5

Item	Value
T1 initial	17°C
T2 initial	16,6°C
Average ambient temperature	21,8°C
Boiler temperature set point	70°C
Average flow boiler	750 ÷ 1000 l/h
Duration of test	3 h
Range data acquisition	5 sec

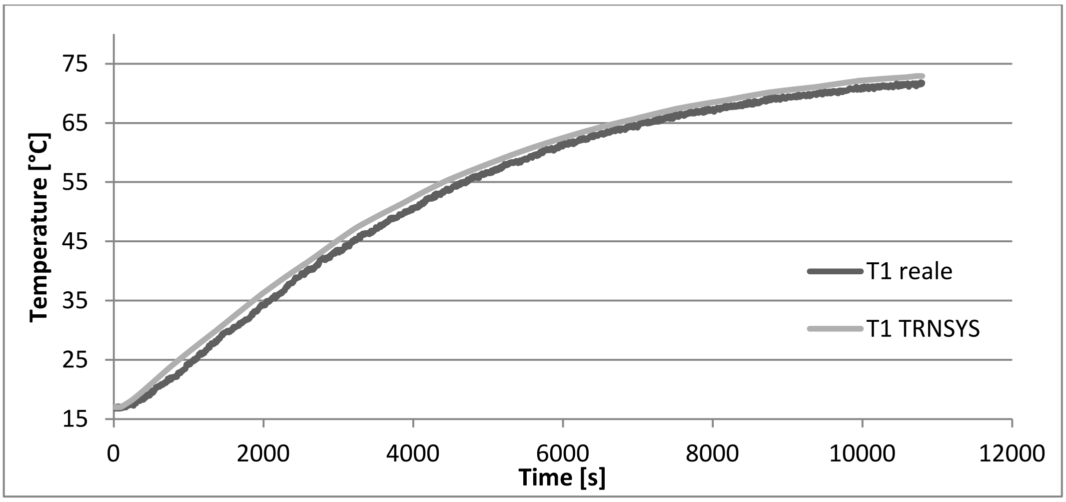


Figure 125. T1 temperature comparison test 5

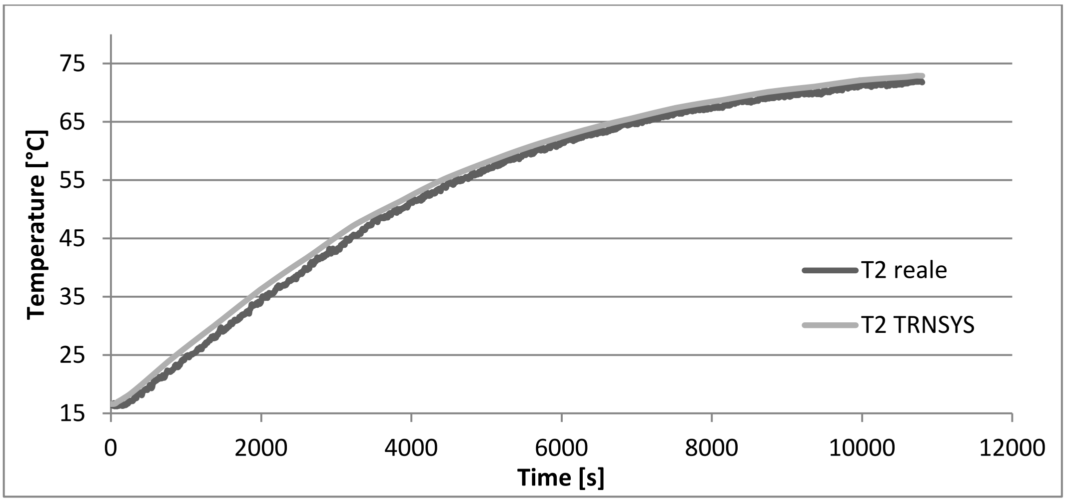


Figure 126. T2 temperature comparison test 5

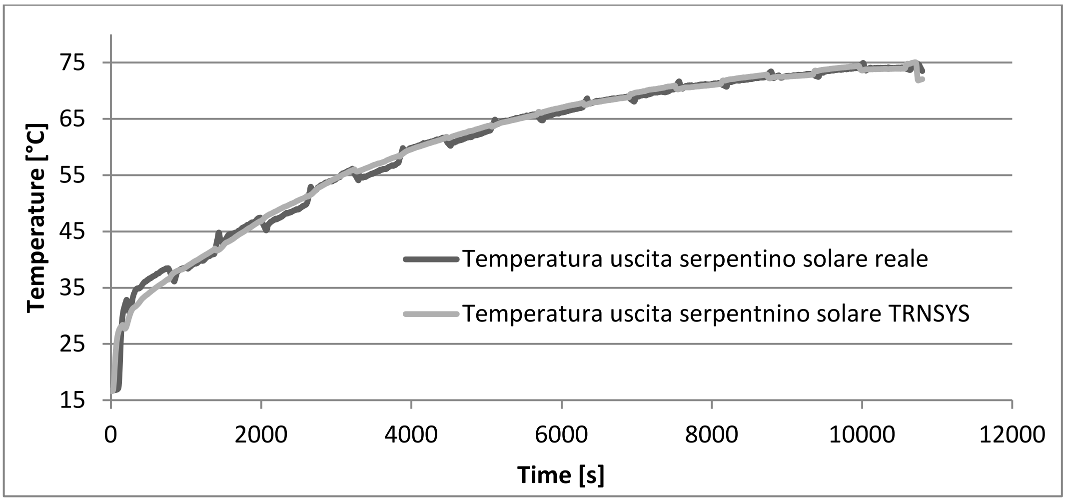


Figure 127. Outlet temperature of the boiler coil after the calibration of the Test 5

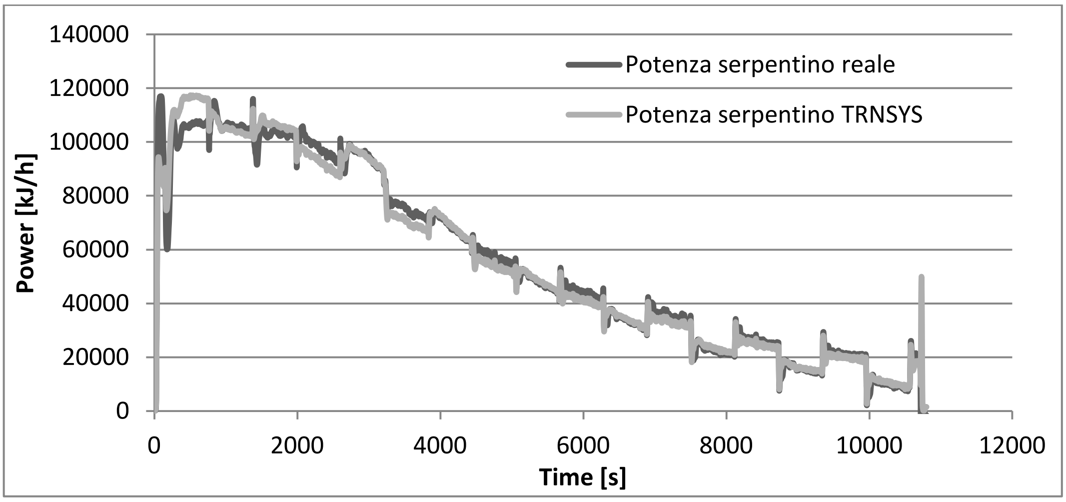


Figure 128. Exchanged power comparison of the boiler coil after the calibration of the Test 5

The results highlight how the software tends to have a response to a variable flow rate and temperature trend less sensitive than the measures, in fact the variations of the temperature and of the power output of the coil have a fairly gradual trend without the strong fluctuations that occur in the real case. This can induce a relevant error, especially in that cases where the solar system works with variable flow pumps.

A.3.6 *Test 6: Heating Test by the means of the boiler coiled heat exchanger and contemporary s withdrawal of DHW, from a balanced initial condition*

The test performer present several similarities with the test 4, but also important differences, like as the set point temperature of the boiler that was increased, and the fact that the temperature of the tank inner volume has been carried to an equilibrium state of about 70°C.

Table 185. Initial conditions and parameters Test 6

Item	Value
T1 initial	71,2 °C
T2 initial	71,4 °C
Average ambient temperature	24,4 °C
Boiler temperature set point	70 °C
Average flow boiler	750 l/h
Temperature set point thermostatic valve	50 °C
Average flow a.c.s.	1000 l/h
Duration of test	3 h
Range data acquisition	5 sec

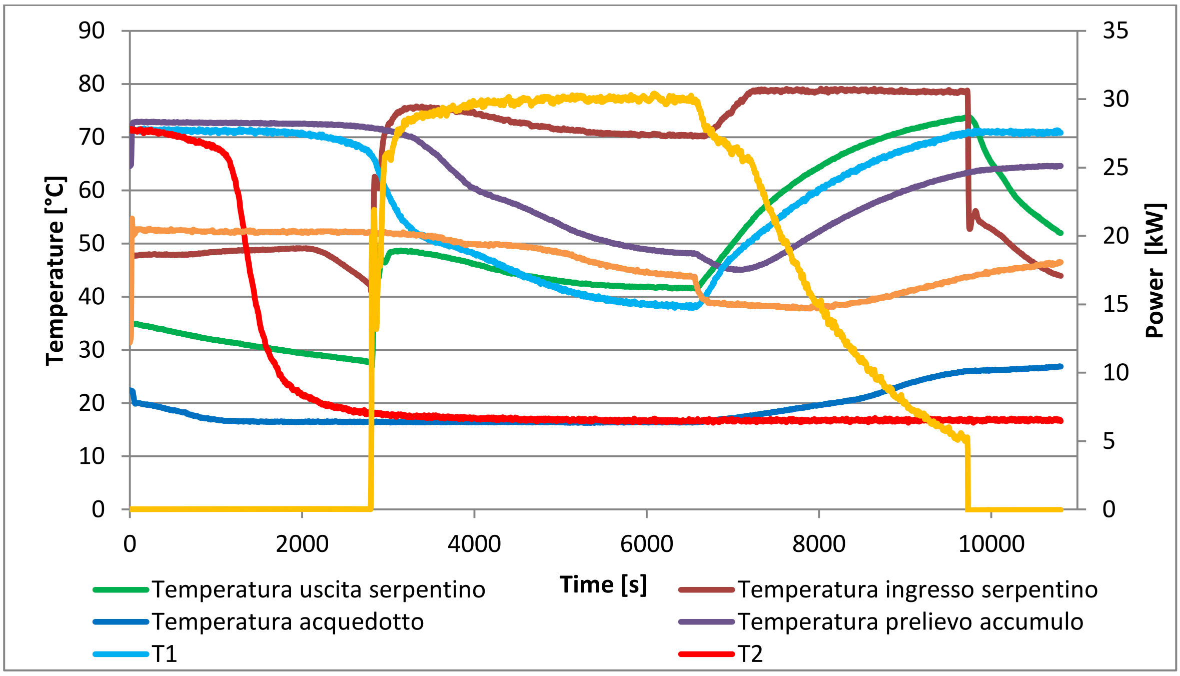


Figure 129. Test 6 Results

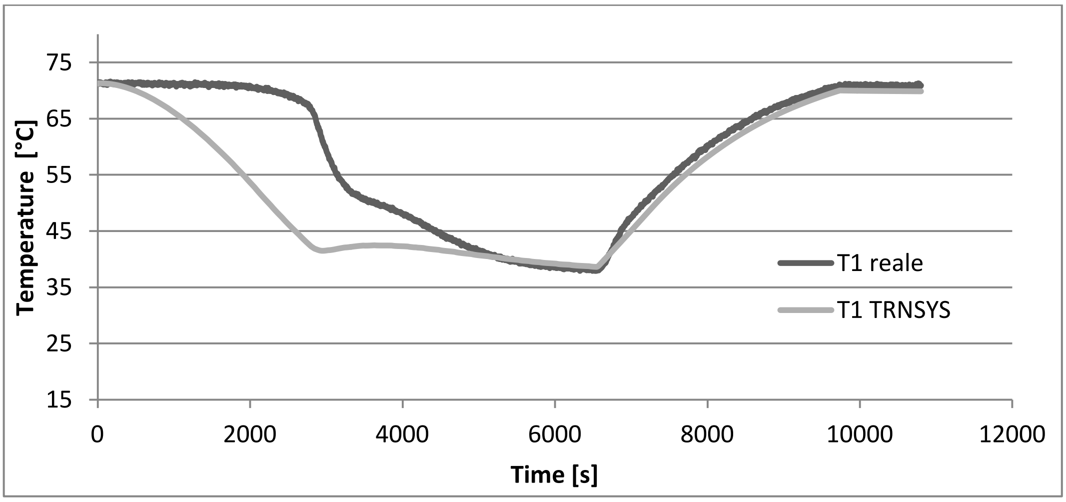


Figure 130. T1 temperature comparison Test 6

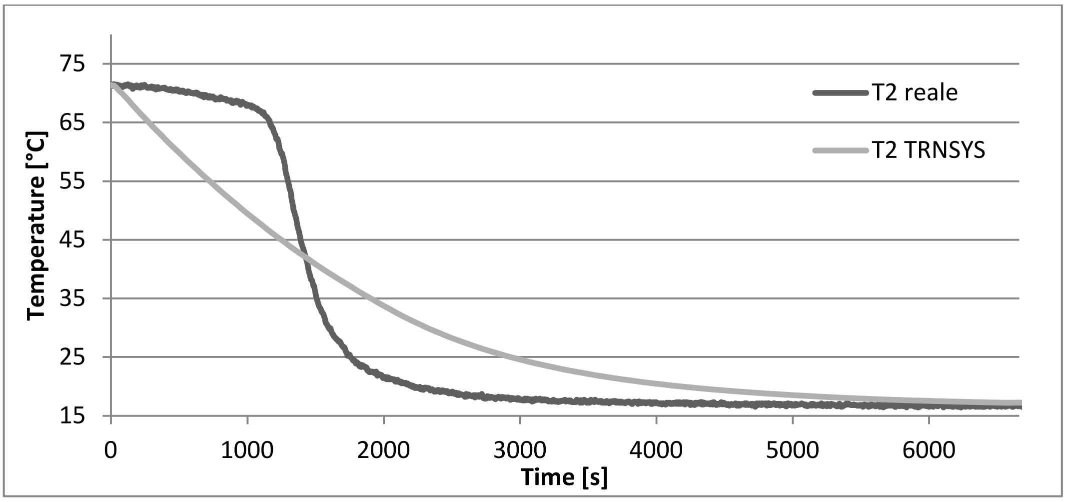


Figure 131. T2 temperature comparison Test 6

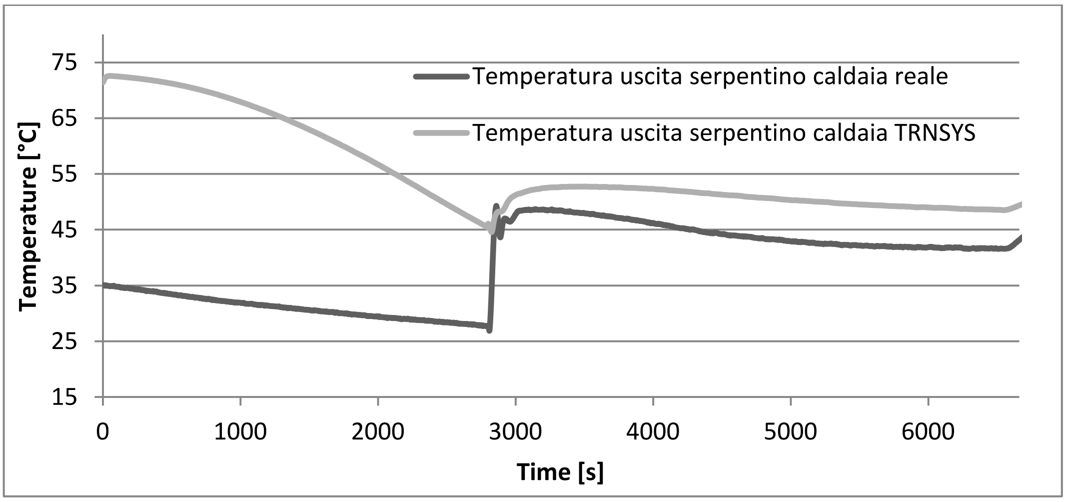


Figure 132. Outlet temperature of the boiler coil Test 6

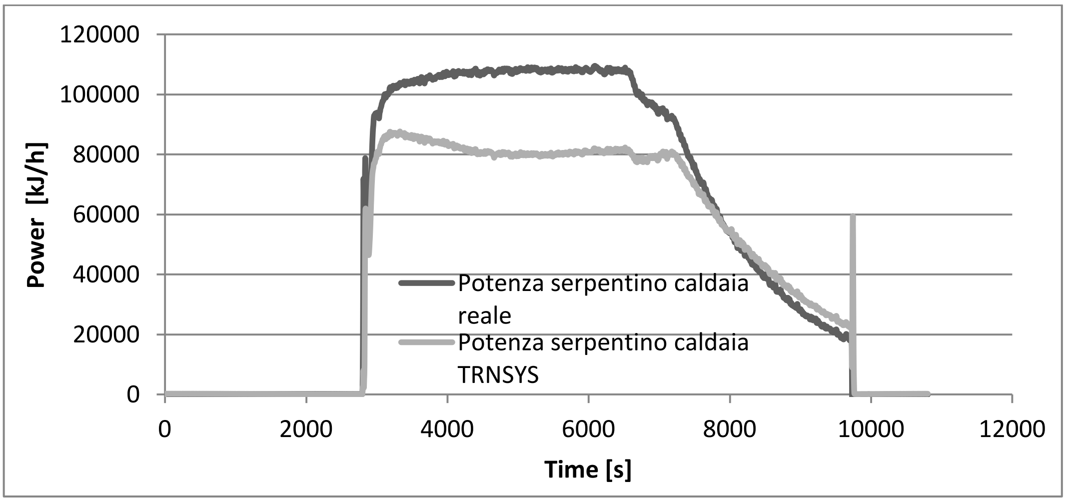


Figure 133. Exchanged power comparison of the boiler coil Test 6

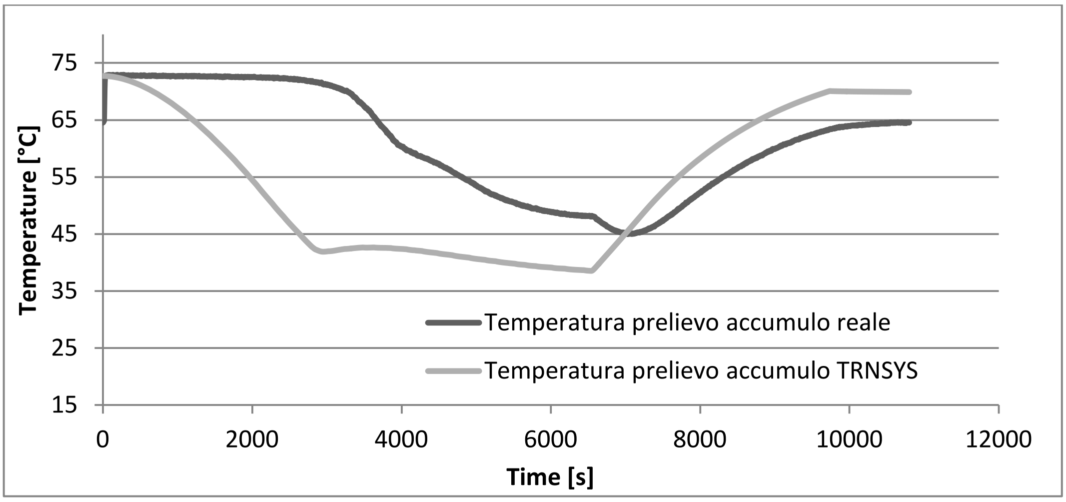


Figure 134. Withdrawal temperature comparison Test 6

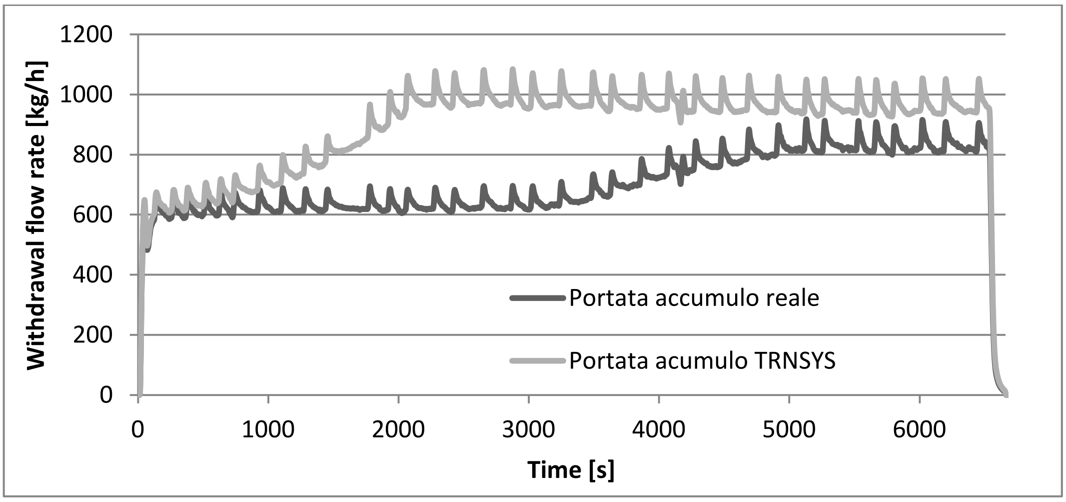


Figure 135. Withdrawal flow rate comparison Test 6

Results show how the simulation tend to under estimate the heat Exchange through the coil of the boiler. In fact the model records a power lower that the measures, with a maximum difference evaluated in 64241 kJ/h i.e. 18 kW. After 30 minutes of simulation, the model presented an outer withdrawal temperature lower than the desired, being not able to satisfy the DHW demand.

A possible explanation could be an not enough detailed modelization of the tank. The inner volume has been divided into 4 nodes, probably to low to achieve a proper dynamic analysis of the storage in the operative condition of this test. To resolve this problem, the simulation has been repeated modeling the tank by the means of 20 nodes, the maximum number allowed by the software. Results of the simulation carried out with the detailed storage tank model are presented in Figure 136 to Figure 141.

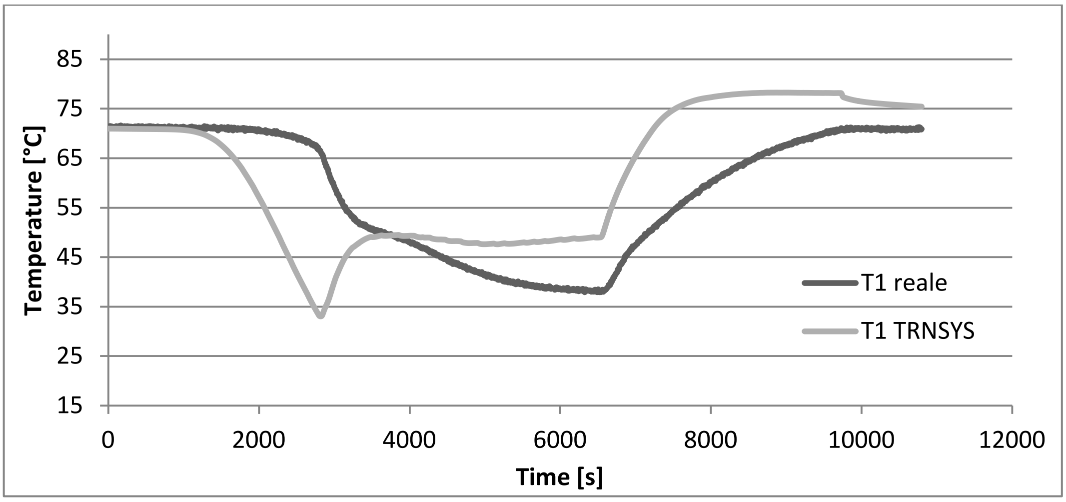


Figure 136. T1 temperature comparison Test 6 -20 nodes

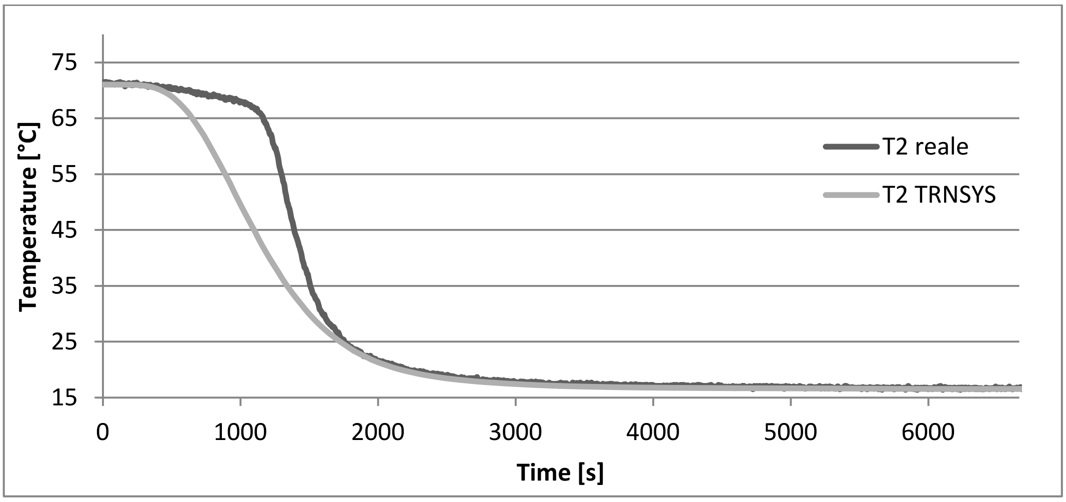


Figure 137. T2 temperature comparison Test 6 -20 nodes

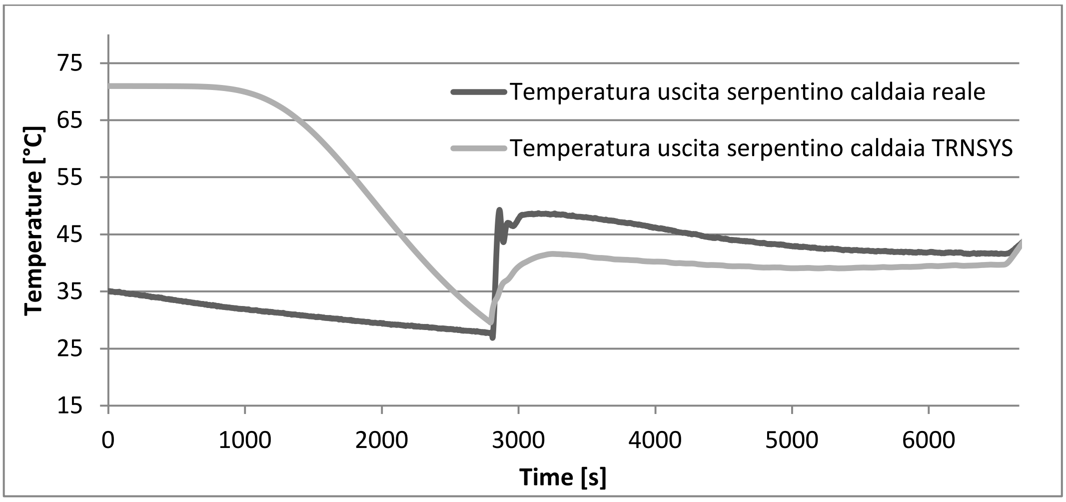


Figure 138. Outlet temperature of the boiler coil Test 6 -20 nodes

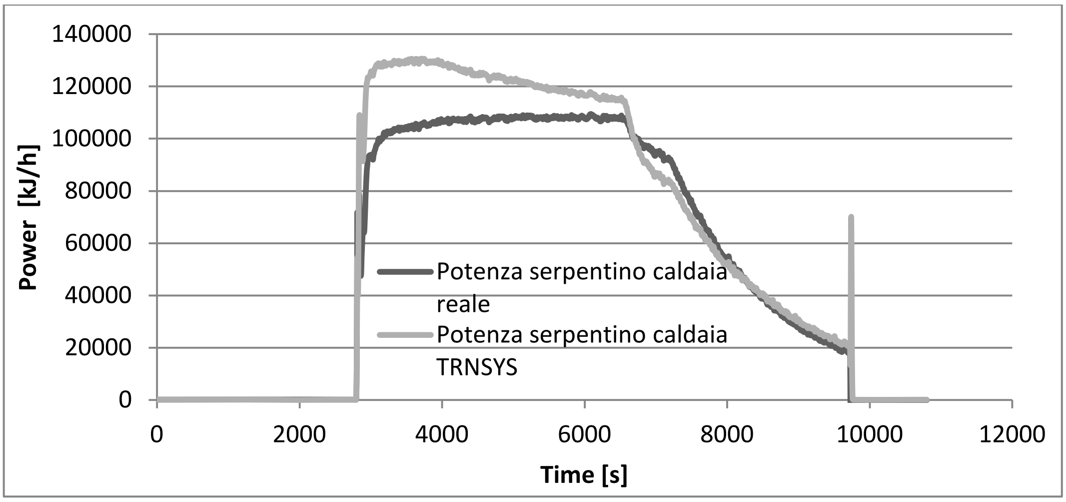


Figure 139. Exchanged power comparison of the boiler coil Test 6- 20 nodes

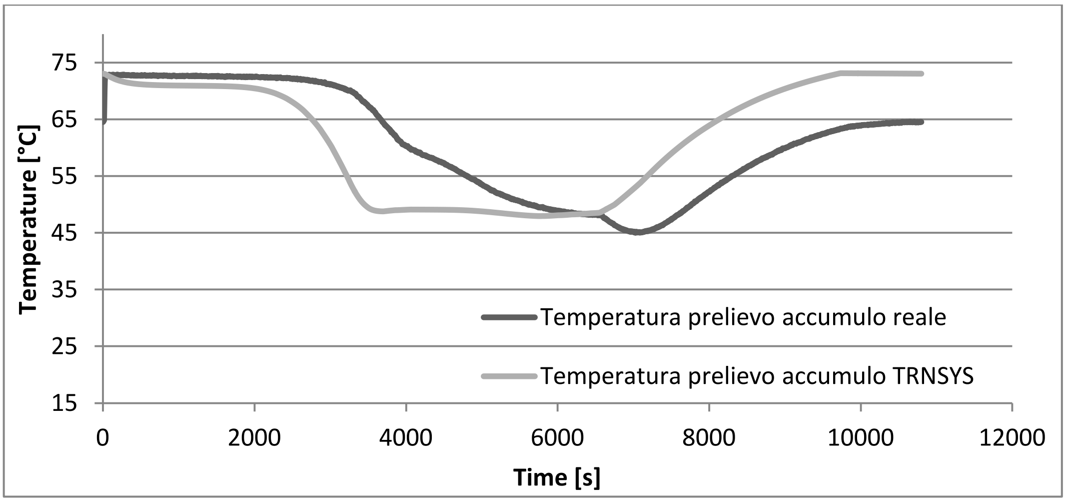


Figure 140. Withdrawal temperature comparison Test 6 – 20 nodes

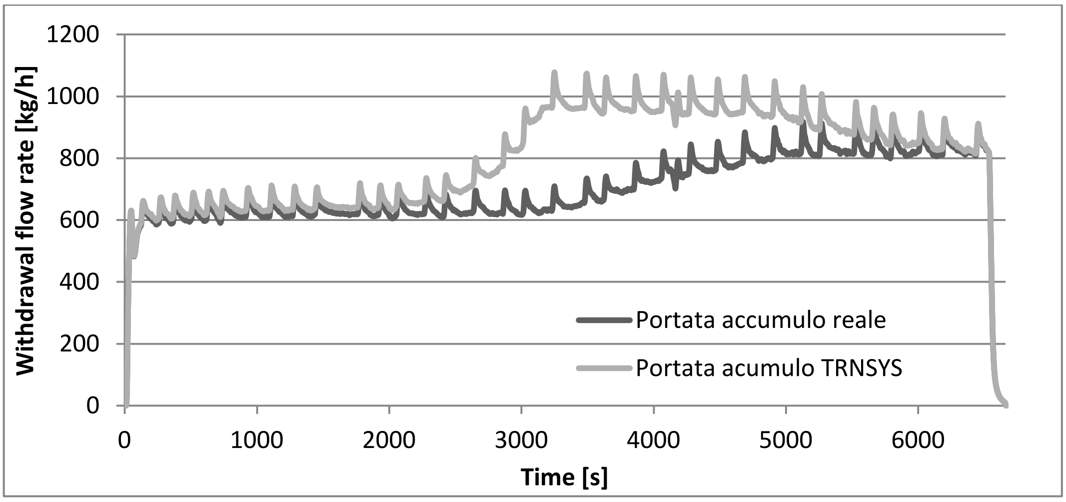


Figure 141. Withdrawal flow rate comparison Test 6 – 20 nodes

This operation was made possible by the fact that the tank was placed in the initial conditions of thermal equilibrium, and it was thus possible to assign to each node the same initial temperature without making significant errors. The temperature T1 was assigned to the node 7 and the temperature T2 to the node 14.
This last simulation aimed to calibrate the system, in order to achieve a better match between the simulation results and the reality. The response of the model to the cold water flow coming from the aqueduct has been improved, so the bottom section of the tank was simulated with a better match respect to the measures. In the upper section of the tank is still evident an higher mixing effect which cause a decrease of the temperature T1 respect to the reality. Results are presented in Figure 142 to Figure 147.

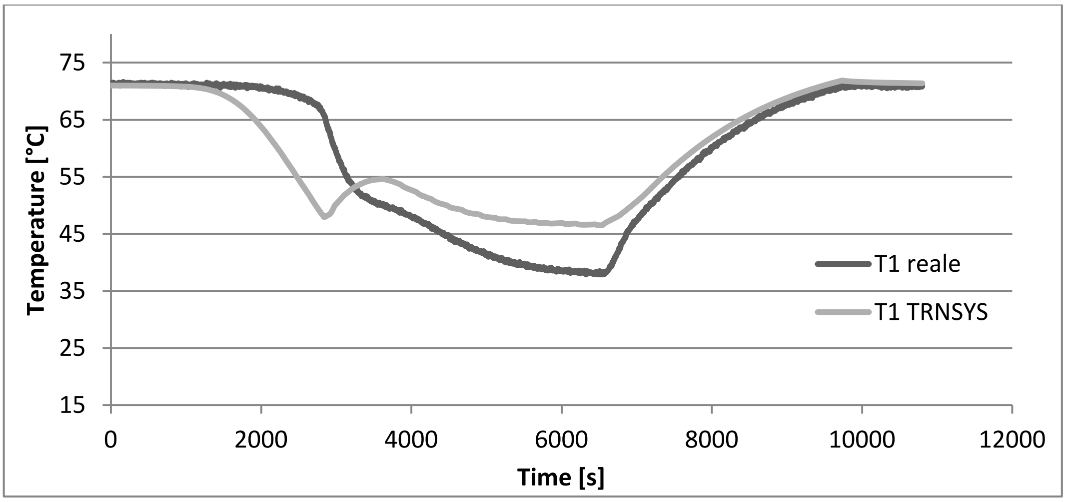


Figure 142. T1 temperature comparison after the calibration of the Test 6 -20 nodes

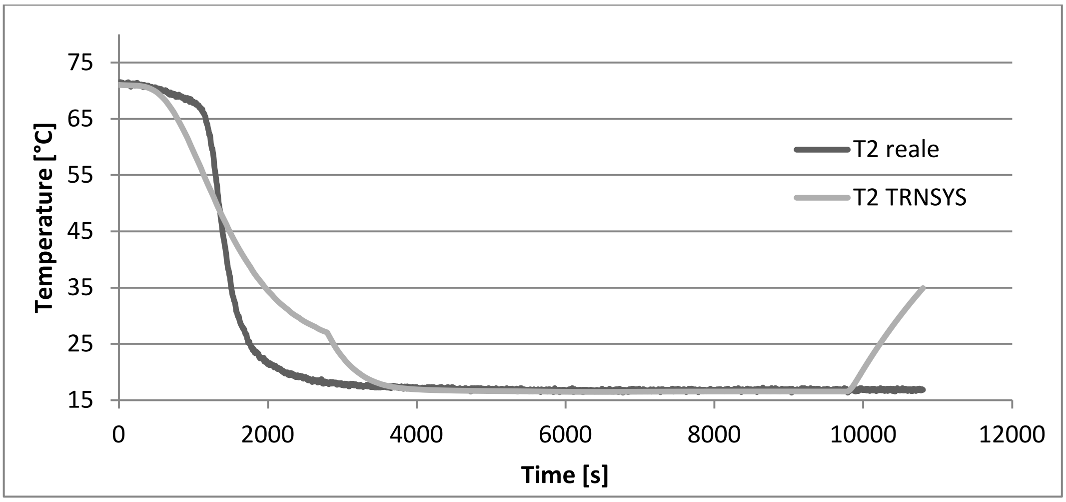


Figure 143. T2 temperature comparison after the calibration of the Test 6 -20 nodes

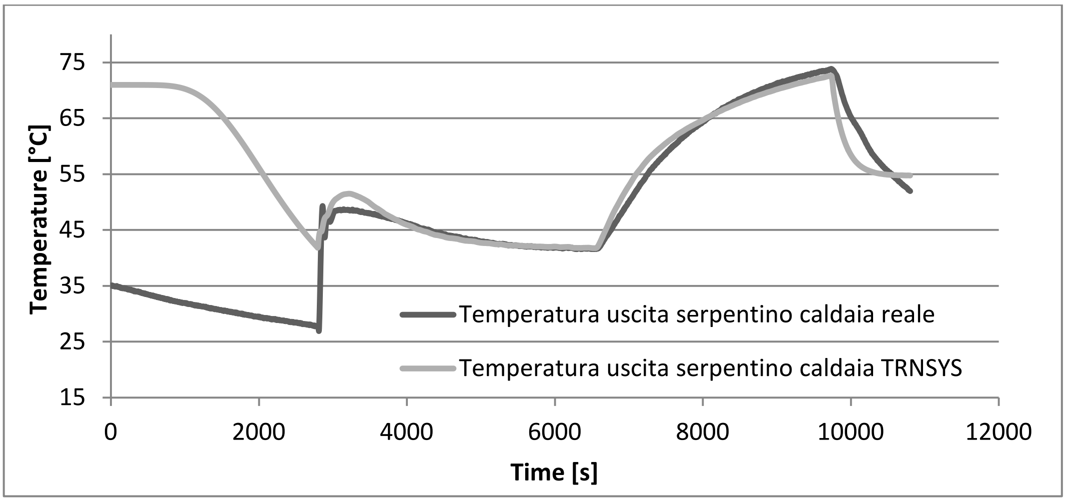


Figure 144. Outlet temperature of the boiler coil after the calibration of the Test 6 -20 nodes

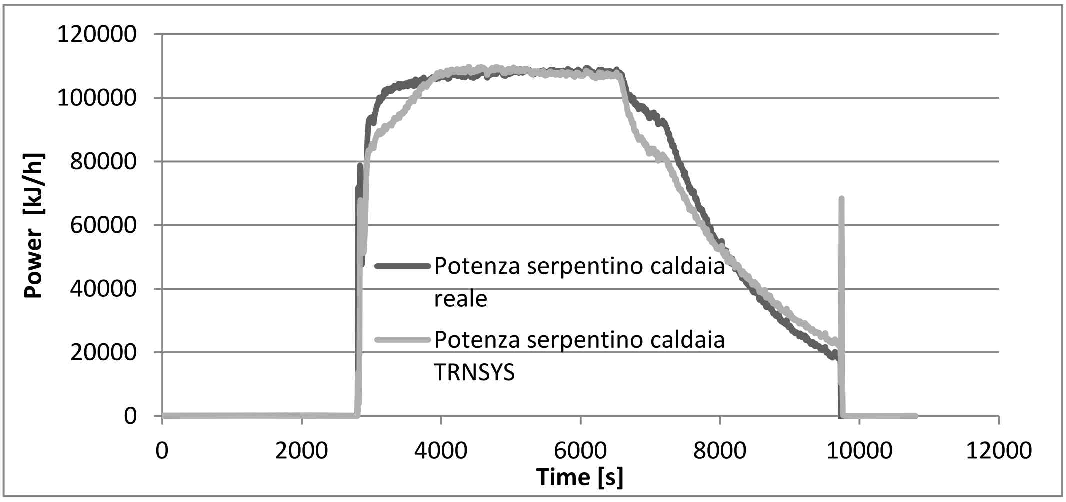


Figure 145. Exchanged power comparison of the boiler coil after the calibration of the Test 6 -20 nodes

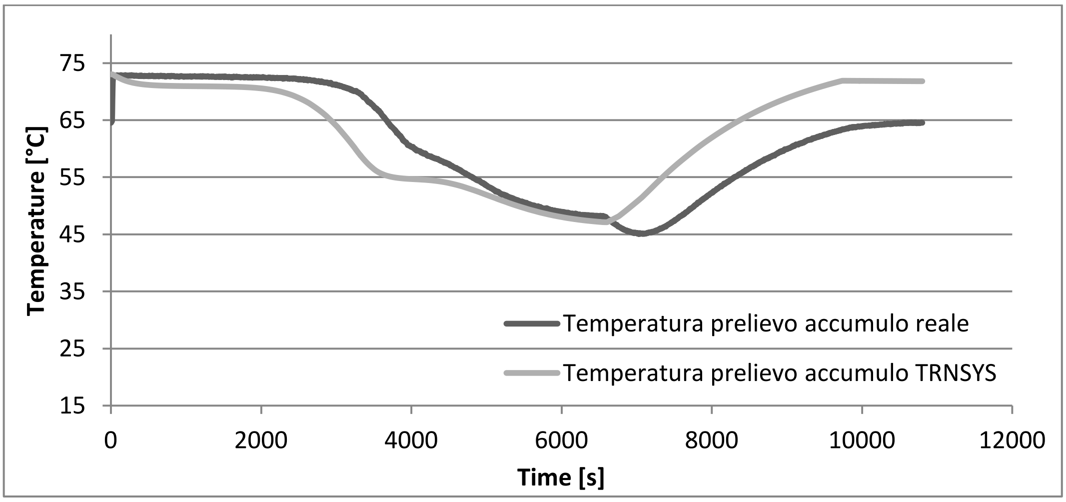


Figure 146. Withdrawal temperature comparison after the calibration of the Test 6 – 20 nodes

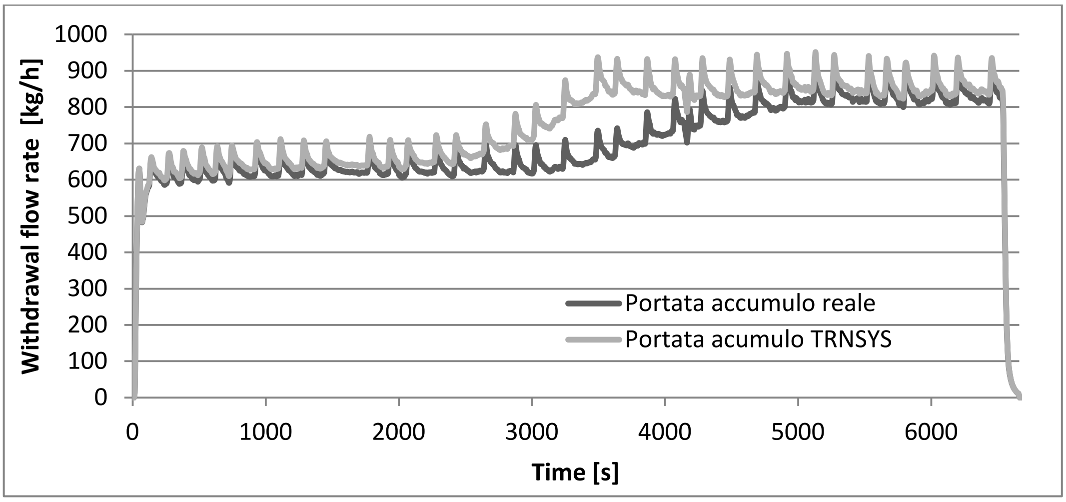


Figure 147. Withdrawal flow rate comparison after the calibration of the Test 6 – 20 nodes

A.3.7 *Test 7: Heating Test by the means of the boiler coiled heat exchanger and contemporary s withdrawal of DHW from the upper junction and with variable flow rate*

The performed test is similar to the former, but in this case the withdrawal of DHW has carried out with two flow rate values. Initially the flow is set equal to 750 l/h and later it has been increased till 1000 l/h.

Table 186. Initial conditions and parameters of the Test 7

Item	Value
T1 initial	72,1 °C
T2 initial	71,9 °C
Average ambient temperature	23,4 °C
Boiler temperature set point	70 °C
Average flow boiler	750 l/h
Temperature set point thermostatic valve	50 °C
Average flow a.c.s.	700 ÷ 1000 l/h
Duration of test	2 h
Range data acquisition	5 sec

This simulation confirms that, modeling the tank with two nodes, the coil is not able to meet the needs of DHW compared to the real case, where such a request is guaranteed even when the flow rate of DHW to produce is higher than 1000 l/h.
Given the initial conditions of thermal equilibrium accumulation has been able to perform the calibration using the same procedure used in the previous test.
From the results is known as the trends of the temperatures T1 and T2 are not completely consistent with the real case, this is most likely due to the fact that it was not obtained a state of thermal equilibrium at the start of the boiler. However, the performance of the power and temperature at the outlet from the tank can be considered reliable.

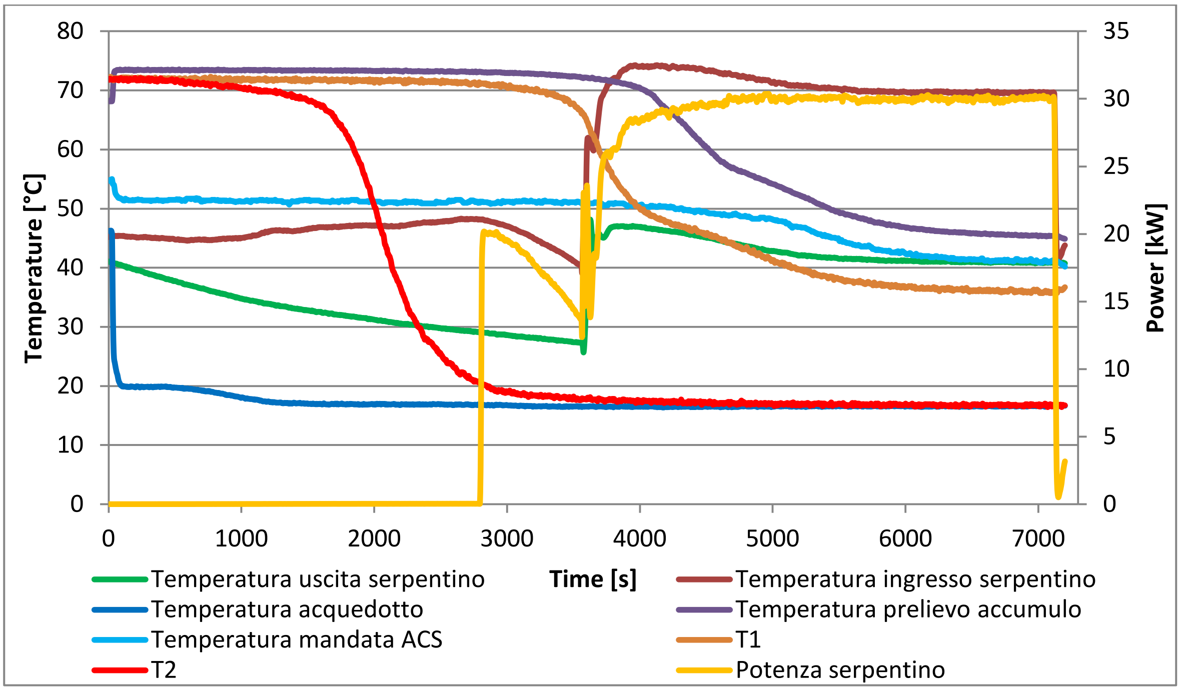


Figure 148. Test 7 results

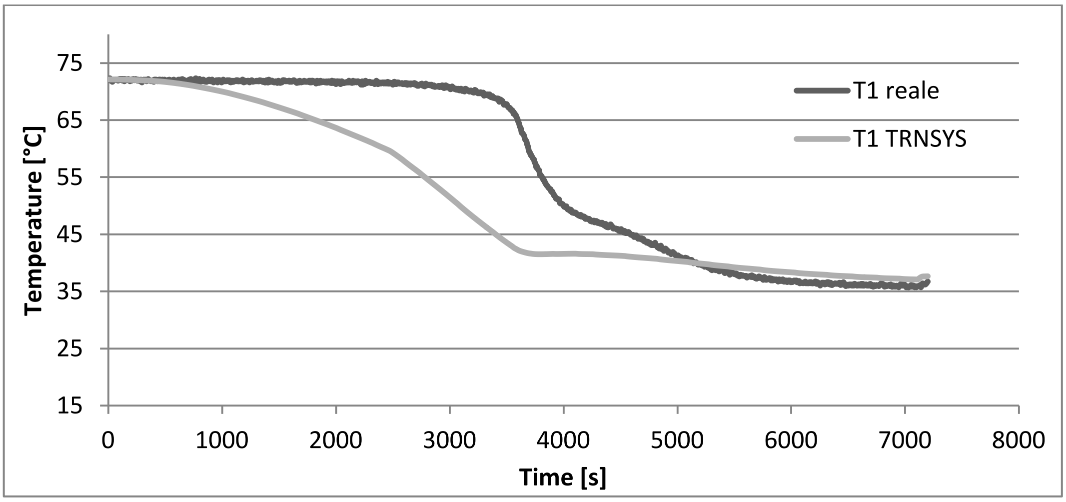


Figure 149. T1 temperature comparison Test 7

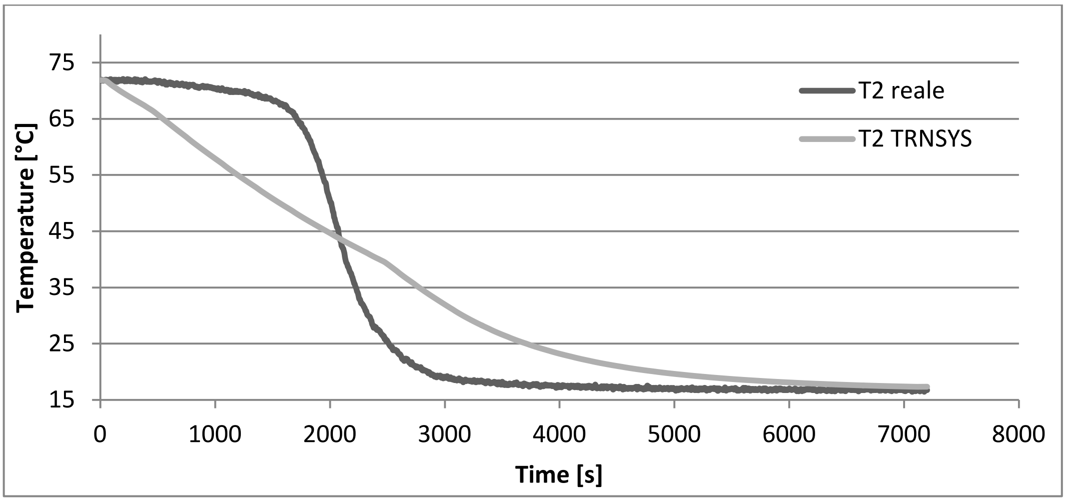


Figure 150. T2 temperature comparison Test 7

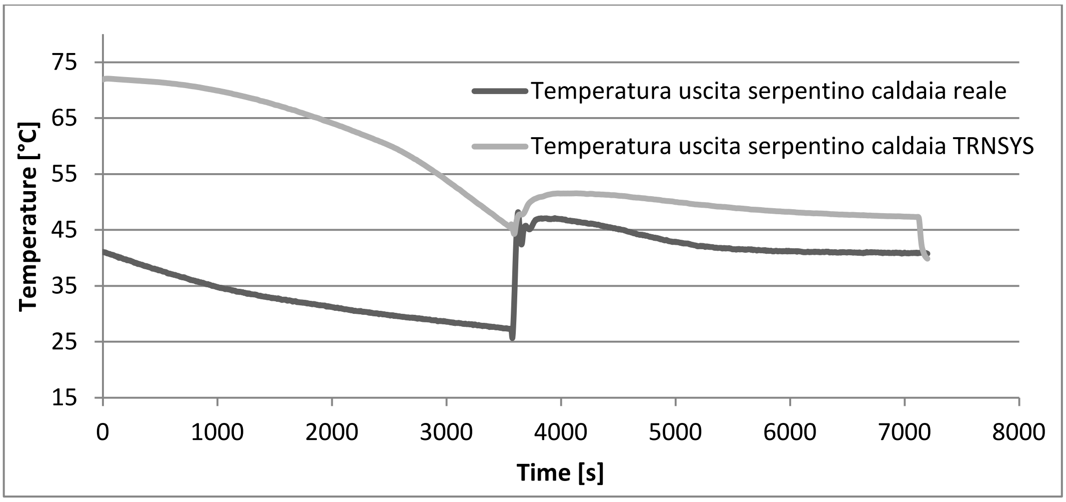


Figure 151. Outlet temperature of the boiler coil Test 7

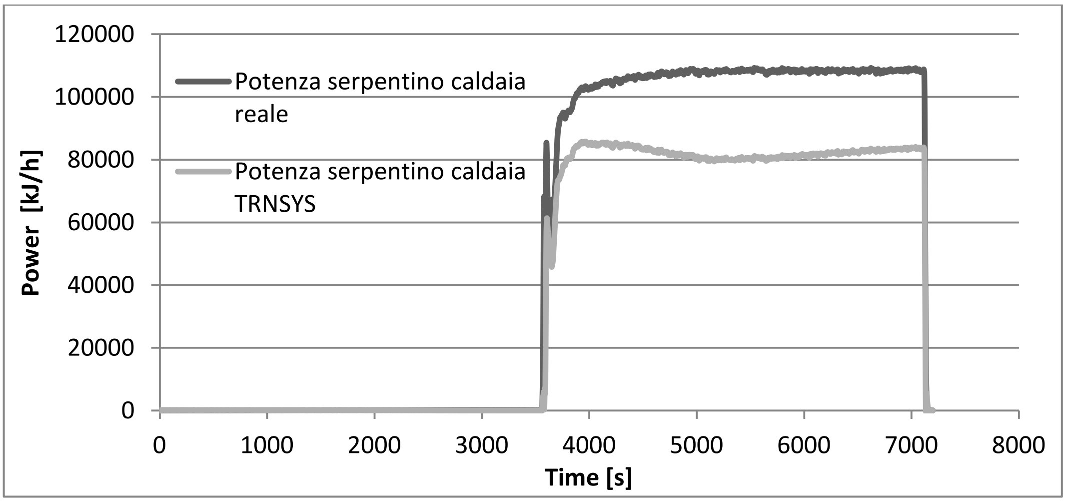


Figure 152. Exchanged power comparison of the boiler coil Test 7

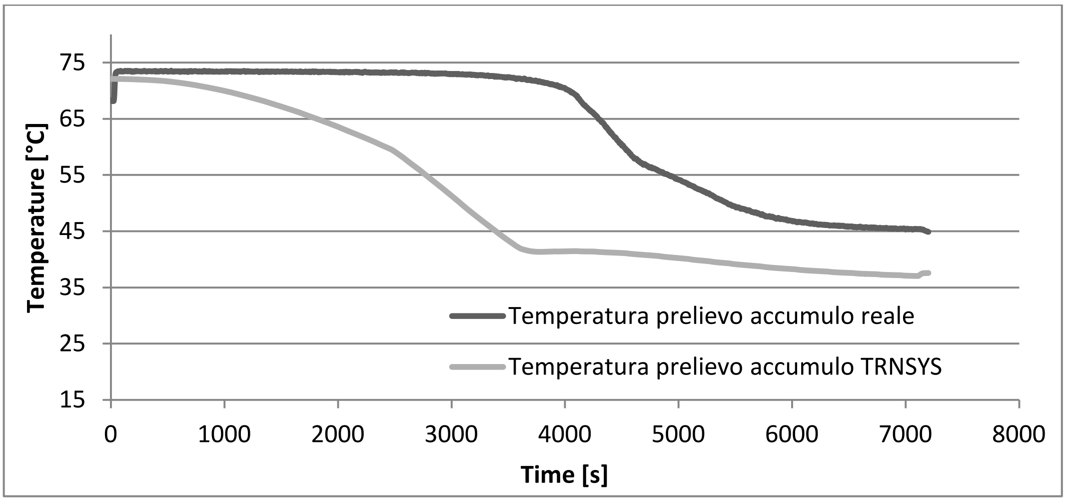


Figure 153. Withdrawal temperature comparison Test 7

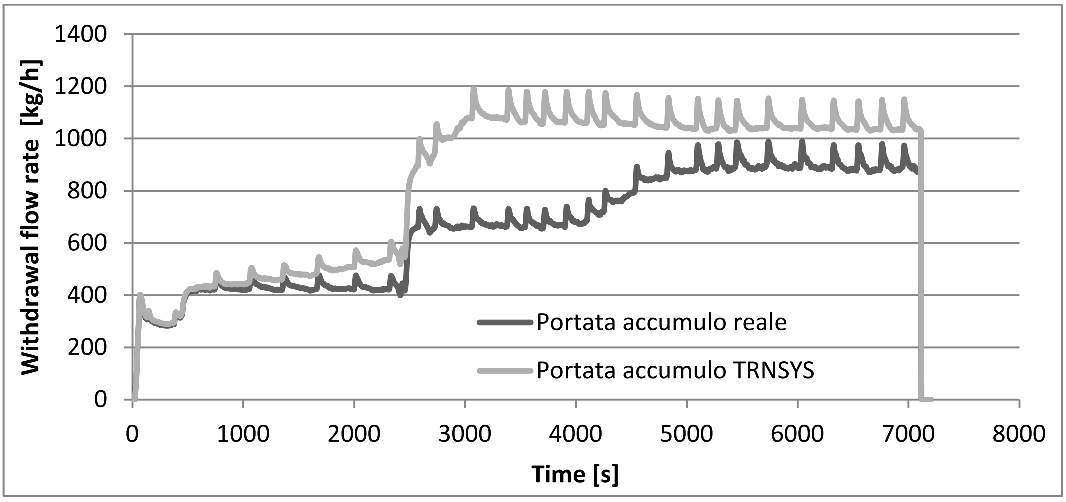


Figure 154. Withdrawal flow rate comparison Test 7

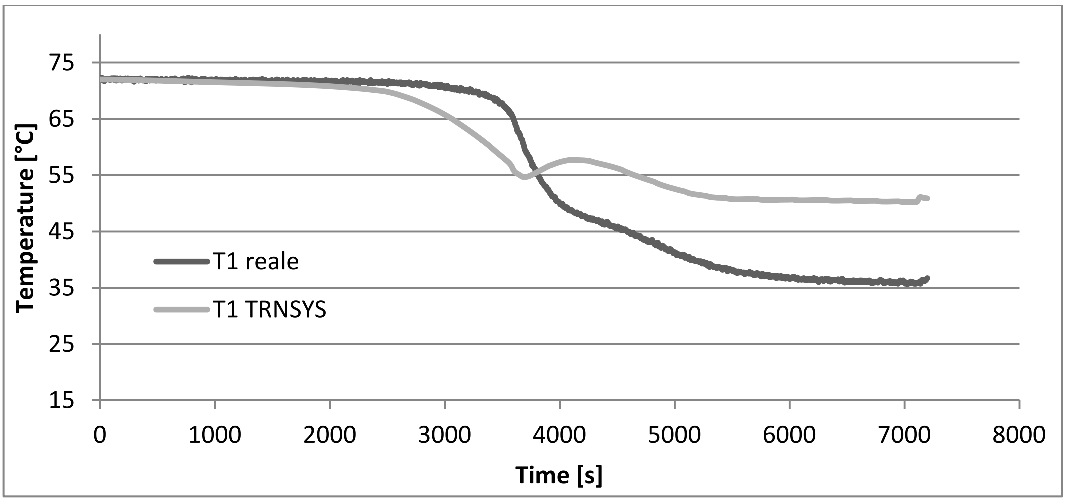


Figure 155. T1 temperature comparison after the calibration of the Test 7 -20 nodes

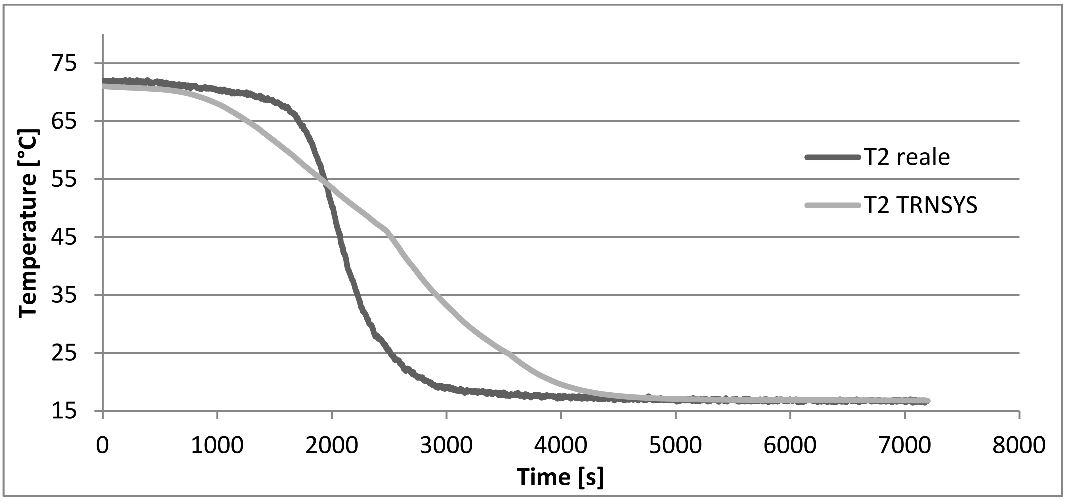


Figure 156. T2 temperature comparison after the calibration of the Test 7 -20 nodes

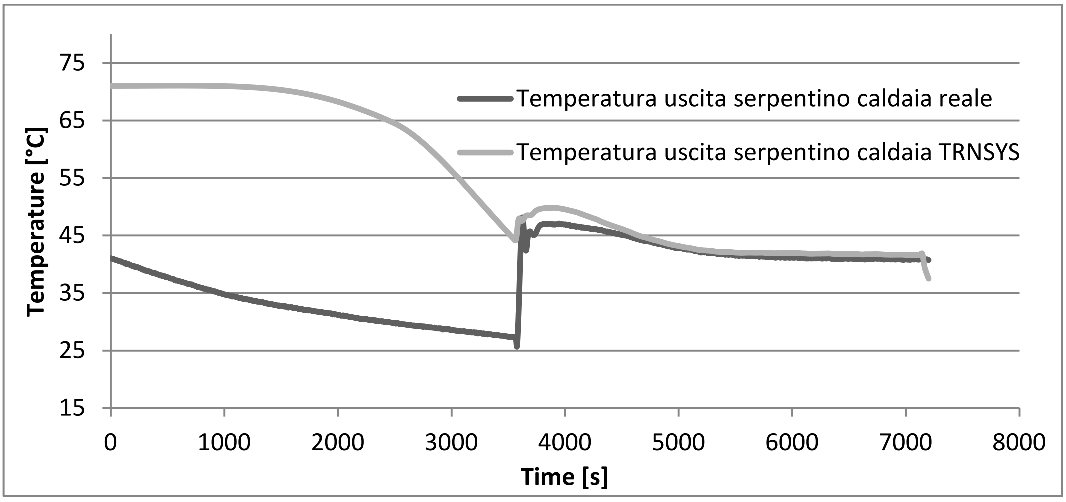


Figure 157. Outlet temperature of the boiler coil after the calibration of the Test 7 -20 nodes

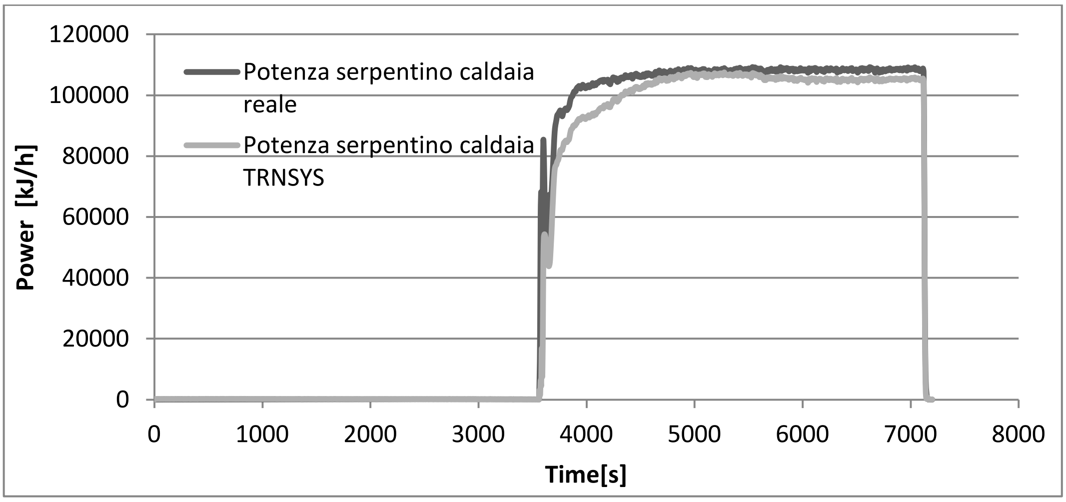


Figure 158. Exchanged power comparison of the boiler coil after the calibration of the Test 7 -20 nodes.

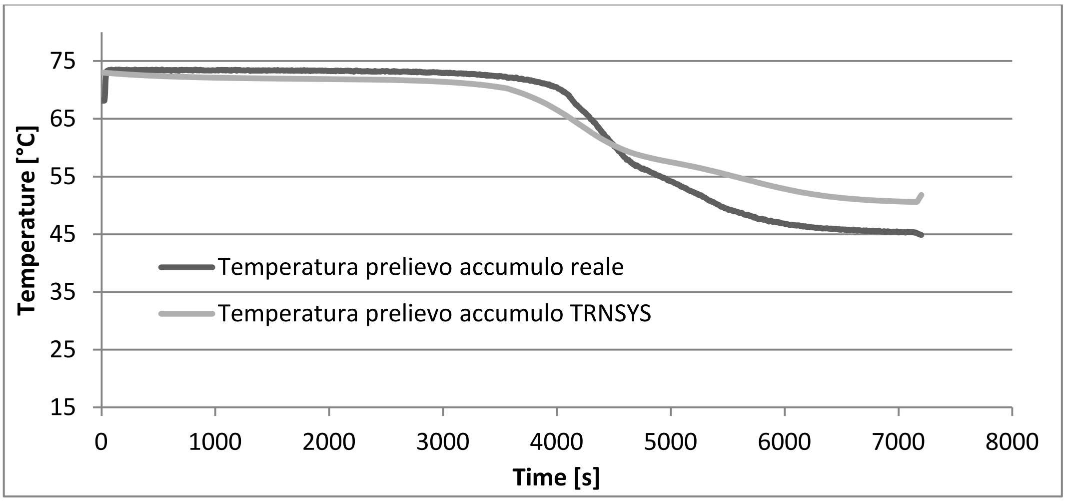


Figure 159. Withdrawal temperature comparison after the calibration of the Test 7 – 20 nodes

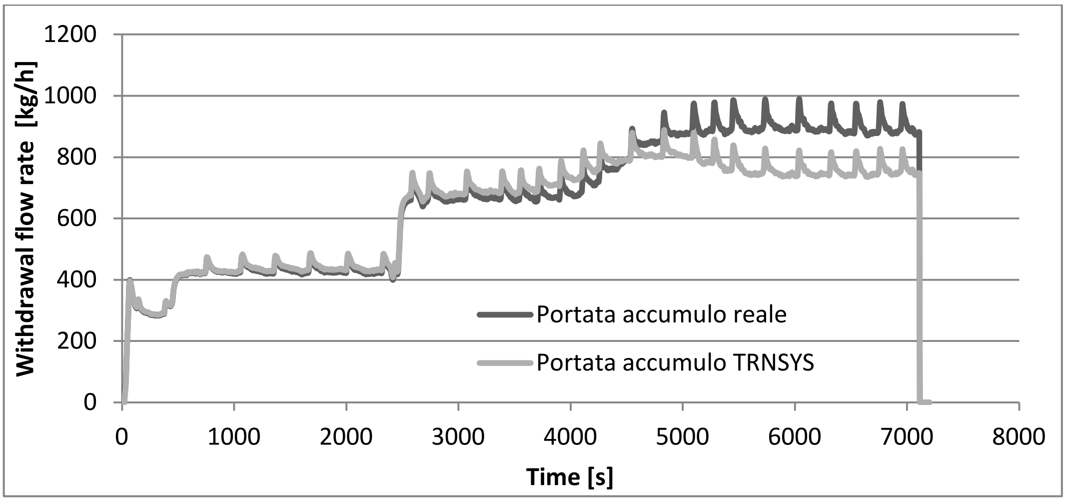


Figure 160. Withdrawal flow rate comparison after the calibration of the Test 7 – 20 nodes

A.4. References

[1] C. BONACCINA, A. CAVALLINI, L. MATTAROLO, Trasmissione del calore, *Cleup Editore,* 1992

[2] M. MARIOTTI, Appunti di termotecnica energia solare termica,*Dipartimento di Fisica Tecnica - Università degli Studi di Padova*

[3] C. ZILIO, Misure e Regolazione Termofluido dinamiche Parte 3 *Dipartimento di Fisica Tecnica Università degli Studi di Padova*

[4] L.ROSSETTO, Dispense di Termodinamica, *Dipartimento di Fisica Tecnica Università degli Studi di Padova*

[5] G.L. MORINI, Miscele aria-vapore, *Dipartimento di Ingegneria Meccanica - Università degli Studi di Ferrara*

[6] E. ZANDEGIACOMO, Appunti di trasmissione del calore, *Dipartimento di Ingegneria Industriale - Università degli Studi di Trieste*

[7] G. MAURI, L. CROCI, D. MONETA, G. LAPINI Funzioni di automazione a supporto dell'efficienza nella termoregolazione degli edifici, *Cesi Ricerca*

[8] C.M. JOPPOLO, L. MOLINAROLI. Legionella, impianti idrici e di condizionamento, *Dipartimento di Energetica - Politecnico di Milano*

[9] TRNSYS 16 Mathematical Reference, *Volume 5*

[10] TESS Library reference, Storage Tank LibraryTechnical Reference, *Volume 11*

[11] TESS Library reference, Parameter Input Output Reference Manual, *Volume 15*

[12] CALEFFI, Gruppo di regolazione a punto fisso per pannelli radianti,*www.caleffi.it*

[13] KLOBEN, Scheda tecnica premix v-max, *www.kloben.it*

[14] ENDRESSER HAUSER, *www.it.endress.com*

[15] DECRETO LEGISLATIVO 3 marzo 2011, n 28, Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE, *www.parlamento.it*

[16] DELIBERA EEN 3/08,Aggiornamento del fattore di conversione dei kWh in tonnellate equivalenti di petrolio connesso al meccanismo dei titoli di efficienza energetica, *www.autorita.energia.it*

[17] DECRETO LEGISLATIVO 30 maggio 2008, n. 115, Attuazione della direttiva 2006/32/CE relativa all'efficienza degli usi finali dell'energia e i servizi energetici e abrogazione della direttiva 93/76/CEE, *www.parlamento.it*

[18] DECISIONE DELLE COMUNITÀ EUROPEE18 luglio 2007, Linee guida per il monitoraggio e la comunicazione delle emissioni di gas effetto serra ai sensi della direttiva 2003/87/CE del Parlamento europeo e del Consiglio, *www.minambiente.it*

ACKNOWLEDGMENTS

I would like to thank the collaborators who have allowed me to carry on the presented studies, in particular Dr. M.C.Menini and Eng. F.Macchi who lead the company Sime S.p.a and the Eng. M.Mantovan leader of Hiref S.p.a. for having supported the activities of research presented in the third chapter. I need to thank also the staff who directly worked with me, the Eng. M.Avanzi and the Eng. A.Zerbetto for the constant assistance and fruitful discussions on the operation of the HVAC systems, and E.Mantovani and the Eng. M.Magnani who allowed the experimental measurements on the thermal storage presented in the Annex A.

I would like to express my special appreciation and thanks to my advisor Professor Dr. Michele De Carli, for the support and the advices provided in these years of collaboration, and to the Professor R.Zecchin for his valuable suggestions. A special thanks goes to my colleague Eng. G.Emmi, for always coming with an answer to my questions, even when they are absurd. I can't forget my others colleagues and friends, V.De Giuli, C.Peretti, A.Mazzari, M.Pasqualetto and A.Benato for the countless exchanges of opinions, the discussions, the coffee breaks and for the forbearance and support in the most tenses moments of this path.