UNIVERSITY OF PADUA

DEPARTMENT OF INDUSTRIAL ENGINEERING
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Study of Trends in Europe of Application Cooling for Multi-Family Houses

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Contents

Introduction

The present document reports the analysis developed for Uponor GmbH about trends of cooling systems in Europe for multi-family buildings. The temporal arch examined was agreed in the thirty years period ranging from 2000 to 2030; it emerges as a study projected on two time horizons, one past and one future, as well as on two main thematic fields, both technical and economic. First, the report evaluates developments and progressions that describe the past decade; the study of the same is essential in order to identify and comprehend criteria that are expected to drive further future evolutions. In the realization of a truthful prognosis, opinions and considerations coming from some experts have been indispensable; the same, thanks to their experiences and skills, have been a fundamental support for having success in the target. Some of the main internal and external interviewees are listed:

- Bravo Eva
- Bogicevic Milos
- Aho Ilari
- Dellwig Stefan
- Vogel Andreas
- Vogel Thomas
- Lipinski Johann
- Rokicki Wojciech
- Kaye Sarah
- Vagiannis Georgios
- Schirrmann Natalia
- Babiak Jan
  - De Carli Michele
  - Olesen Bjarne
  - Kurnitski Jarek
  - Gava Simone

As previously anticipated, a double matrix, technical and economic, has been adopted as tool to describe cooling trends in Europe. On one hand, the study evaluates domestic cooling systems, highlighting operative features and principals, applications' advantages and disadvantages, and recognising criteria pursued by manufactures in order to promote further technological improvements. On the other hand, the analysis focuses on main European markets, examining and interpreting successes of selected cooling technologies as results of social, political, economic and environmental influences. Many are the external factors that should condition technological improvements and market positions of products. Therefore, scope of the study is also to define boundary conditions that justify recorded and forecasted trends. The combination between technical and economic considerations gives to Uponor GmbH tools to evaluate if its products are under or over-engineered, as well as to identify further competences needed in order to fit technical and market's requirements in 15 years.

I. Abstract

Although the international financial crisis of last few years, the European residential cooling market still manifests as dynamic and with great potential. On one side, the European scenario is deeply based on heating rather than on cooling and this make the same to be currently less developed compared to China, Japan and US. Nevertheless, the same immaturity of the European market is symbol of a great potential, especially speaking about the residential sector, where air conditioning penetrations are still far from the ones that describes the commercial segment. Therefore, there is a huge growth's margin, especially in Countries that did not experience positive trends in the beginning of the present millennium as Mediterranean nations did. On the other side, indeed, spotlights are slowing moving away from latter regions that have been protagonists so far, for concentrating attentions to other participants, which are increasing market's positions. Specifically, the study recognizes France and Germany, as well as Eastern Europe and Southeast Europe as areas where the domestic cooling demand is expected to expand in the next decade. Economic reasons, considerations on climatic anomalies recorded in past summers and prognosis about future residential construction industry are supporting the forecast.

Several requisites emerge from the technological analysis; specifically speaking about multi-family applications, systems are developing towards centralized solutions that provide both heating and cooling. In addition, multiple integrated functions are required, which means that domestic plants have also to guarantee fresh air ventilation (mandatory in new low-energy buildings) and dehumidification/humidification of the primary air. Further interactions with DHW systems and domestic solar power plants are expected. These results will have some effects on generators and emitters. As regards the former, electrically driven heat pumps are supposed to spread especially in Central Europe as alternative to combustion boilers; reversible heat pumps operate in both winter and summer. The spreading of such generators might push the success of reversible hydronic emitters, like fan coils and radiant panels (UFH&C). Focusing on the latter, manufactures might look for plug-and-play products that should reduce the design phase, which is making radiant panels more expensive and far from costumers; the simplification of the design phase is supposed to make the distribution of the products in the market easier. At the same time, also split technology is evolving toward centralized and reversible systems. In particular, mini-splits, together with fan coils, are supposed to have great success in Countries where prerequisites of cheapness and installation

facility are going to be predominant also for the next decade, respectively in Southern and Eastern Europe. Radiant technology, on the contrary, might gain a prestigious position in Central Europe, where better domestic construction industry's forecasts, wealthier conditions and the larger spread of hydronic heat pumps are likely favouring the same.

II. Residential Cooling Context

Residential cooling matter is going on playing a more important role since many years, mainly thanks to high rising demand that has interested many of the European Members. The cooling demand is included in global residential consumptions; as building sector covers the 40% of the final energy demand in Europe, and residential demand is more or less the 60% of the latter, it is easy to understand why an increasing trend, as air conditioning one, has to be taken into consideration and under observation. In the past two decades, the residential sector has been under monitoring, with different actions projected to the reduction of consumptions, both thermal and electrical. The target is to limit the environmental impact of the domestic needs, on one hand decreasing the energy demand, and on the other hand suppling the left energy with renewable sources. The European Commission has promoted different regulations up to now, with the aim to make aware European Members about the necessity to face up to this problem and to stimulate the same to solutions which could contemporaneously safeguard national economic and environmental stability. In the following pages, an analysis of the main European regulations, which deal with domestic efficiency, of both building and appliances, is proposed. However, a heavy increase of air conditioning installations is a phenomenon that is in total contraposition to the context in which it is included. If one side there is an evident tendency to make the sector less energy intensive, on the other side the community have to face with an ascendant penetration of air conditioning devices, which inevitably lead to more consumptions. Hence, it is fundamental to understand how the cooling issue might insert into a scenario, which sees energy efficiency, energy saving and renewable sources as keywords.

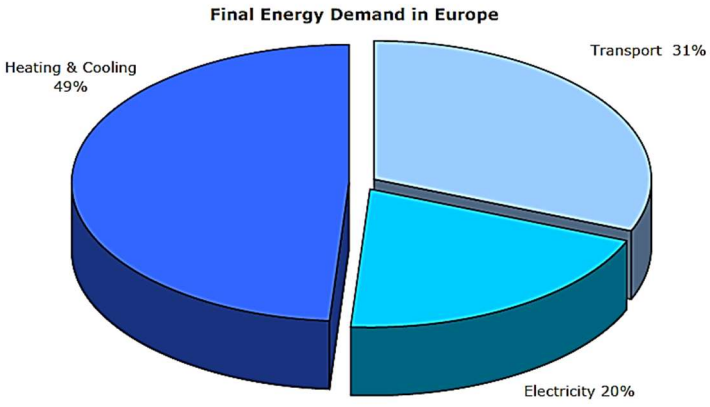


Figure 1- Final Energy Demand in Europe (Source: EREC 2006)

From another point of view, one should underline the importance of what into consideration since heating and cooling cover the half of the final energy demand in Europe.

Report on market situation & trends about small-scale chillers suggests that 30-35% of thermal consumptions is linked to building stock and the 70% of this is for space heating. On the other hand, it is quite complicated to estimate cooling role, since it is mostly incorporated into the electricity load; however, in *Ecoheatcool (2005)*, cooling load, in EU-15, is said to be the 8% of the electricity one with a high rate of growth.

An investigation on the reasons why the cooling demand in the residential sector has experienced a positive gait in the past years might be convenient for proposing a more complete study. Furthermore, the comprehension of the factors that have driven this ascendant trend might make one able to interpret the phenomenon in a deeper way, in addition to the ability to make a prognosis, which takes into consideration the influences of the past. The strong and constant growth of the application cooling's market has been stoked by the cultural trend towards comfort, wellness and health. The increase of economic European citizens´ wealth has made people to take care about their physical conditions inside their dwellings with lots of interest. In other words, the improvement of life conditions in economic terms have led to a consequent changing in primary needs. In particular, if in the past comfort requests were linked only to a close group of people, since some decades these have become more common extending to the middle class.

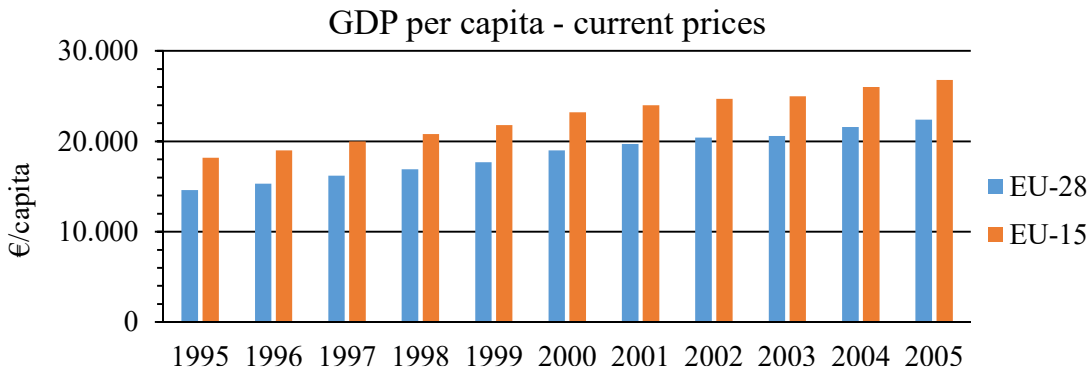


Figure 2 – GDP per capita (Source: Eurostat data)

Report on market situation & trends about small-scale chillers reports the following emblematic sentence: "The lifestyle and growing wealth require high comfort conditions in everyday activities which are very difficult to be neglected and given up by the end-users". This aspect has been evident for cooling as of heating; the need of a warm house has always represented the base of civil living, but only in the modern period air-cooling has started to play an important role too. Therefore, one can identified comfort expectations of a wealthy population as the main driver for the growing cooling demand for the domestic sector in Europe; furthermore, it is clear how the availability of cooling applications has facilitate the

spread of the same into residential buildings. Nevertheless, other two significant factors can be recognized as promoters of ascendant cooling loads. The first is related to the fact that new and refurbished buildings must meet requirements in terms of insulation. In order to reduce energy demand for space heating, regulations have imposed limits to insulation of new and refurbished dwellings through the years, becoming stricter and stricter. Direct consequence of this is the increasing of the cooling load; since the house is becoming more insulated, there will be more need to reduce temperature during summer, as the requirement of the fresh air ventilation. The other factor is recognized in warmer temperatures, which are making summer cooling a matter of luxury no more.

III. European Legislation Affecting Air Cooling

In the last decades, EU governments have developed several politic guidelines in order to promote a triple target, that is to say more renewables, more energy efficiency and fewer emissions. The push toward environmental friendly solutions has been many times in contrast with economic matter; even if the authorities have worked on some incentives in energy efficient technologies, as well as a more penetration of renewable sources, the difficulty to face on households' propensities toward cheaper alternatives has been strong. In other words, the path focused on the previous three targets seems to be expensive and, because of this, the changes' process is revealing quite slow. Nevertheless, European legislations has been fundamental in order to stimulate a stronger inclination in order to improve energy saving and efficiency, as well as the use of renewable sources.

The present chapter would like to give an update on the development of the European policy framework that effects heating and cooling sector in general. Indeed, all the legislations that deal with efficiency, emissions' reduction and renewable energies have inevitable consequences on the heating and cooling market, as well as for technological further developments. In particular, the present study considers the following legislative acts:

1. EPBD
2. RES Directive
3. EED
4. Energy Labelling Directive
5. F-Gas Regulation

In general, one should recognize that all these regulations promote the use of renewable and more efficient systems, fixing minimum requirements necessary for achieving the reduction of greenhouse gas emissions.

3.1 Energy Performance Building Directive

The EPBD directive (2010/31/UE) concerns the energy performance of buildings, both residential and public, incentivizing national governments to a more awareness toward global energy consumptions due to the mentioned sectors. In particular, the target is to promote an improvement on both the new-build and existing stock by reducing the final energy demand

for thermal needs. EU Members are invited to develop measures in order to improve the residential energy performances, according to an optima-cost method. In other words, European Nations have to identify which is the better way to be successful in the present goal, combining energy efficiency with cheapness of solutions. In case of excessive discrepancy, Nations have to plan measures in order to reduce it. The focus is both structural and technological, that is to say that interventions on building's elements and energy systems have to be taken into consideration. How might the EPBD influence cooling applications and market?

- The EPBD directive makes national governments to fix minimum energy efficiency requirements in case of huge refurbishment and requalification of existing edifices. It means that, in general, some operations for better insulation level, both for walls and windows, are supposed, as well as renovations of heating and DHW systems. It is probable that more insulation will lead to an increasing cooling demand during summers. However, one should remember that these limits are in case of refurbishment, which is not mandatory. Different considerations are, on the contrary, for new houses because they all have to respect energy performance requirements established by authorities.

- Speaking about new habitations, the directive suggests improving energy performances of the same by promoting low-energy buildings diffusion and the increasing spread of nZEBs until 2020, after which all new houses have to be in the last mentioned configuration. On one hand, it is clear that the directive privilege the reduction of each kind of energy demand; it means that the European Commission has recognized a deep growth of residential air cooling applications and has established that it is fundamental to improve the edifice's operation also during summers. In other words, Nations have to prefer solutions as free cooling and shading devices, which avoid the overheating during warmer seasons. On the other hand, this aspect should not lead to a reduction of the cooling market, which on the contrary seems to benefit from airtight habitations. Because of this, also mechanical ventilations is expected to become a necessity in order to ensure air quality and to avoid moulds during winter. Nevertheless, it is useful to underline that mechanical ventilation might be not enough in order to supply the energy demand of

nZEBs. If we consider input air's temperatures of about 40°C in winter and 16°C in summer, with an air change rate of 1 vol/h, the corresponded power should be of 13.8 W/m^2 and 9.2 W/m^2 respectively. Considering that the best performances of nZEBs are around 25-50 W/m^2 and 20-40 W/m^2 in the cold and warm seasons, one should recognize that only the mechanical ventilation systems is not suitable for fulfilling building's needs. Further problematics emerge when we consider also the latent load and hence the control of humidity. This the reason why it should be declared that with the only ventilation it is not possible to control the comfort level and, therefore, heating/cooling plants will be still present. However, it is evident on one side the necessity to have systems suitable for lower demands, and on the other side, that cooling need are becoming more significant in the energy context of an edifice.

- Another important aspect deriving from the EPBD deals with the promotion of alternative and high-efficiency plants, as cogeneration, district heating/cooling (especially if it based on renewable sources), decentralized energy supply systems based on renewable sources, and heat pumps. From that, one might identified the probable trend also in the cooling market to promote solutions that combine high efficiency and the use of sources. In particular, for this purpose, in my opinion reversible heat pumps driven by renewable power should play a fundamental role in the next decades.

3.2 Renewables Directive

The RES directive (2009/28/EC) establishes a common framework for the promotion of an increasing penetration of renewable energy in global consumptions. In particular, it sets national targets for the share of renewable sources in the gross final demand, that is to say it includes all segments, from residential to transport's one. The legislation defines energy from renewable sources as the power obtained by wind, solar, biomass and biogas, ocean energy and hydropower, aerothermal, geothermal, hydrothermal. One first reflection is on the last three energy sources, which deal with the energy stored in form of heat respectively in air, solid earth and surface water. Hence, it is evident that the European Commission recognizes the ones mentioned as renewable and, therefore, it promotes heat pumps as green solutions,

especially for space heating and cooling[1]. Indeed, EU Members, and in particular local and regional administrative bodies, shall recommend the spread of systems that supply electricity, heating and cooling from renewable sources as tool to achieve minimum fixed levels of the same in new and existing buildings that are subject to major renovation. Another important topic many times underlined in the RES directive is the promotion of district heating and cooling from renewable energy source when planning/building residential areas.

The most relevant influence that the present legislation has had in the residential sector concerns the development of national renewable energy action plans (NREAPs) that establish limits in terms of share of renewable energy use for the domestic demand. In both new and existing edifices, the thermal system has to fulfil space and DHW heating by partly use renewable souses, as well as it is expected that solar panels produce a share of electric power. Therefore, it is evident that nowadays there is a strong push toward the achievement of green targets and, since it is supposed these minimum requirements should become more restrictive, technological developments have to take into consideration the necessity to respond to these environmental friendly prerequisites. Speaking about heating and cooling, reversible heat pumps, based on renewable sources as air and ground, driven by renewable electricity (PV) and coupled with solar thermal panels, are going to gain the most significant position in the market as integrate and green system able to supply space heating/cooling and DHW. This, in other words, coincides with the abandonment of fuel based domestic plants.

3.3 Energy Efficiency Directive

Together with the increasing use of renewable energies, energy efficiency has been recognized from the European Commission as one of the most important options in order to achieve the reduction of greenhouse gas emissions and so to mitigate climate change. The EED (Energy Efficiency Directive) aims at the improvement of efficiency in many fields and in particular it underlines the fundamental position represented by the building sector. On one hand, the legislation affirms that public authorities and edifices might become an important driver to stimulate market transformation toward products, buildings and services that are more efficient. On the other hand, it is stressed that the EU Members have to promote investments in the residential renovation as the existing stock represents the single biggest potential sector for energy saving. This aspect is so fundamental that also *Roadmap for moving*

[1] The RES directive recognizes heat pumps as renewable generators if their SPFs are over 2.63

to a competitive low-carbon energy roadmap in 2050 suggests that by 2050 an emission reduction by 80% is feasible through reduction in the energy domestic demand and the European Parliament highlights the importance of a huger focus on the heating and cooling segment. It is evident the impact that the EED should have on the trend toward better energy performances of buildings, as well as for appliances and space heating/cooling plants.

Another important consideration deals with the great focus that the EED and RES put on cogeneration and the decentralized distribution of heating and cooling. The European Commission believes that high-efficiency cogeneration and district heating and cooling have significant potential for energy saving and for an incremented use of renewable sources. Nevertheless, the present study thinks that, taking into consideration the huge complexity of the strict requirements' achievement and the relevant role played by the existing stock, a more capillary operative scheme should be useful and suitable.

3.4 Ecolabel and Energy Labelling Directive

The energy labelling directive deals with product labels and information fiches in which details on energy efficiency (class) and consumptions of a product are available. They apply to all energy related products that should have a significant impact on the house's energy demand; air conditioners and in general heat pumps have to be equipped with it. Thanks to technical information, the end-user might be able to identify the most efficient products and compare the same. *European Heat Pump Market and Statistics REPORT* affirms: "in relation to minimum efficiency requirement, only heat pump with an efficiency class A+ and better will be allowed in the market". In other words, the performances of ErPs[2] are going to be transparent, favouring so the diffusion of only high efficiency elements and the comparison between equipment for the same purpose, independently of the energy source used.

3.5 F-Gas

Fluorinated gases consists in PFC, SF_6 and mostly in HFC[3], chemicals used since '90s to replace CFC and HCFC[4] in refrigeration equipment, air conditioning systems and heat pumps. These substances have no impact on ozone but have a high potential for global

[2] ErPs = Energy related products
[3] PFC = perfluorocarbons; SF_6 = sulfur hexafluoride; HFC =hydrofluorocarbons
[4] CFC = chlorofluorocarbons; HCFC = hydrochlorofluorocarbons

warming. Hence, a part from technical criteria, F-gases have to satisfy minimum requisites in terms of GWP (global warming potential). Because of their negative contributions to greenhouse effect, in the last decades new technological solutions based both on F-gases with low GWP and on other substances, such as natural refrigerants and hydrocarbons, have been identified. Furthermore, the European Commission adopted two regulations, 842/2006 and the new 517/2014, in order to limit on one hand the use and the placing on the market of equipment containing F-gases, on the other hand the leakage of these chemicals through proper plants' management. First, the legislation establishes a gradual reduction of 79% of the amount of F-gases placed on the market from 2015 to 2030. Therefore the first impact on residential air-conditioning consists in a reduced availability of HFC (such as R410A, R407C, R32), which moves into a search of new working fluids.

Years	2015	2016-17	2018-20	2021-23	2024-26	2027-29	2030
HFC on the market	100%	93%	63%	45%	31%	24%	21%
Stationary refrigeration systems with HFC with GWP>2500			from 1st January 2020				
Centralized multipack systems for commercial use (capacity over 40kW) con HFC with GWP>150				from 1st January 2022			
Monosplit with less than 3kg with HFC with GWP>750					from 1st January 2025		

Table 1 – Main data for abolition of F-gases (Source: F-gas regulation)

The new regulation of 2014 has changed the limits for the application of obligations, expressing the same no more in kg of gas but in kg of CO_2 equivalent. The normative considers the overall greenhouse effect of each cooling circuit, by multiplying the mass of the refrigerant for the GWP of the same. This means that equipment containing more than 3kg of refrigerant (6kg if hermetically sealed) refers to new limits of tons of CO_2 equivalent, while the others respect the 'old' F-gas until 2017. Speaking about cooling systems within the scope of the present study, monoblock[5] and split devices normally contain from 0.5 to 4kg of refrigerant; the fluid currently most common applied is R410A. On the contrary, multi-splits and heat pumps for domestic use may exceed the threshold of 3kg of refrigerant. For instance, according to what established, annuals controls of losses should be requested for these systems.

Two conclusions can be inferred from the table above:

[5] Monoblock air conditioners are window and portable devices

1. From 2020 all air conditioners that use refrigerants with GWP greater than 2500 are banned; currently, all air conditioning systems use R410A (GWP = 1730) or R407C (GWP = 1530). Daikin has developed a new split conditioner operating with R32 (GWP = 650). Therefore, manufactures should have no particular difficulty to respect limits imposed by law in the next few years.

2. From 2022-2025 the GWP is reduced considerably. Therefore, there is the necessity to find other fluids, such as the R32, that will meet those requirements. Nonetheless, ten years seem to be sufficient for such scope; any negative impact is recognizable in short term.

In summary, technologically speaking, the F-gas directive is promoting the search and the use of alternative low-GDP refrigerants, for air conditioners and heat pumps, which have to meet at the same time chemical, health and environmental, cheapness and performance requisites. Nowadays, we speak especially about ammonia, HFOs and their mixtures, and R32. However, some issues concerning some criticalities, such as security and efficiency, remain linked to the use of the chemicals mentioned.

IV. Historical Review of Space Air Conditioning

The history of building conditioning starts in the 1900s, with big all-air cooling systems. These plants were installed mainly on buildings' roof, since the AHU (air-handling unit), was very bulky and not so aesthetic. The AHU consists in several components: internal elements are shutters, cleaners, heat exchangers, humidifiers and centrifugal fans. The external ones supply hot or cold water, as well as they include distribution and retake ducts. The first step of the handling process is the mixing of internal and external air, which then pass through elements above, where they are handled in terms of temperature, humidity and air quality. Nowadays the all-air systems are used mainly in the North America countries, since there are new buildings, which do not present dimension limits and which are suitable for big distribution ducts and for future plant's changes. In European countries, on the contrary, a new technology, called mixed air-water cooling application, has been spread. The reason is that in Europe there are many old and historical buildings, which need cooling plants with lower aesthetic and dimension impacts. In these systems, the external air is handled by the AHU, while the internal one is treated by final elements, which are supplied by cold water and settled directly inside the rooms. These emitters are fan coil units, induction units or radiant panels. In many cases, it is possible not to install the AHU; a combined action of final elements and small mechanical ventilation systems for fresh air allows reaching comfort conditions required. This configuration is the hydronic cooling one.

In order to minimize the amount of space occupied, all-air systems were deeply developed in order to package all necessary components in just one element, which would be suitable to install in a small place inside domestic walls. Therefore, external components were removed; the new 'all-air system' consists in two fans and a refrigerant circuit, which has the task to chill and dehumidify the air. Thanks to this solution, it was possible to settle smaller plants in residential buildings too; we are talking about "monoblock" and portable all-air conditioners.

The next step is represented by the development of split systems; the split application's merit has been to take the compressor and the condenser, which are the noisiest and bulkiest elements, outside the house, in a metal bin. This solution has removed many complications of "monoblocks", since splits have no noisy and dimension problems, are more efficient and make the costumer free to decide where to install internal units. This is the reason why, until

now, splits have had a deep impact in the cooling market and specifically in the residential sector. Nowadays households think about split air conditioner as an appliance.

In the past few years, radiant cooling application has taken a more important lead too; nevertheless, its market impact has been not as powerful as for heating. However, radiant panels ensure better indoor conditions and high comfort level. This is one of the most significant reasons, as well as its low energy consumption, high efficiency, adaptability to alternative and renewable sources, reversibility for both heating and cooling, that will bring radiant panels to play a more important role in the next decade. The development of air conditioning systems is deeply connected to cooling demand changes, not only in terms of quantity but also for its features. European residential cooling demand has been not comparable to the heating one, first because the need is lower, highly variable from year to year, and largely confined to Mediterranean regions. Nonetheless, many factors are outlining a horizon in which the residential air conditioning demand is increasing, expanding to more European areas, becoming more intense and constant among summer. As a consequence, air conditioning systems are going not to be perceived as simple appliances anymore, but as plant that will cover a fundamental position as heating does. Furthermore, the necessity to safeguard our world and to limit climate changes has imposed a technological evolution based on improvement in efficiency and so reduction of energy consumption, the decrease of heating demand, which brings as consequence the cooling request increasing, and the fulfilment of the two by the use of renewable sources.

V. Classification of Cooling Application

The most common way for classifying cooling application is based on operative fluids, which are described as substances that carry thermal loads as combination of sensible and latent heats. The present study adopts this principle, although it has managed the classification in order make the same more compatible with market data available. Both all-air and hydronic plants need generators (chillers or heat pumps) for the production of cold refrigerant or water. In split and 'monoblock' systems all elements are collected in compact units, in other words generator and emitters are directly connected by the refrigerant plant; on the contrary, in all-air and hydronic configurations, the refrigerant cools down the carrier fluid (air or water), which then flows through distribution ducts or pipes. Therefore, in the technical analysis, as well as in the economic one, chillers and heat pumps are added as generators needed in centralized cooling systems, operating with air or water.

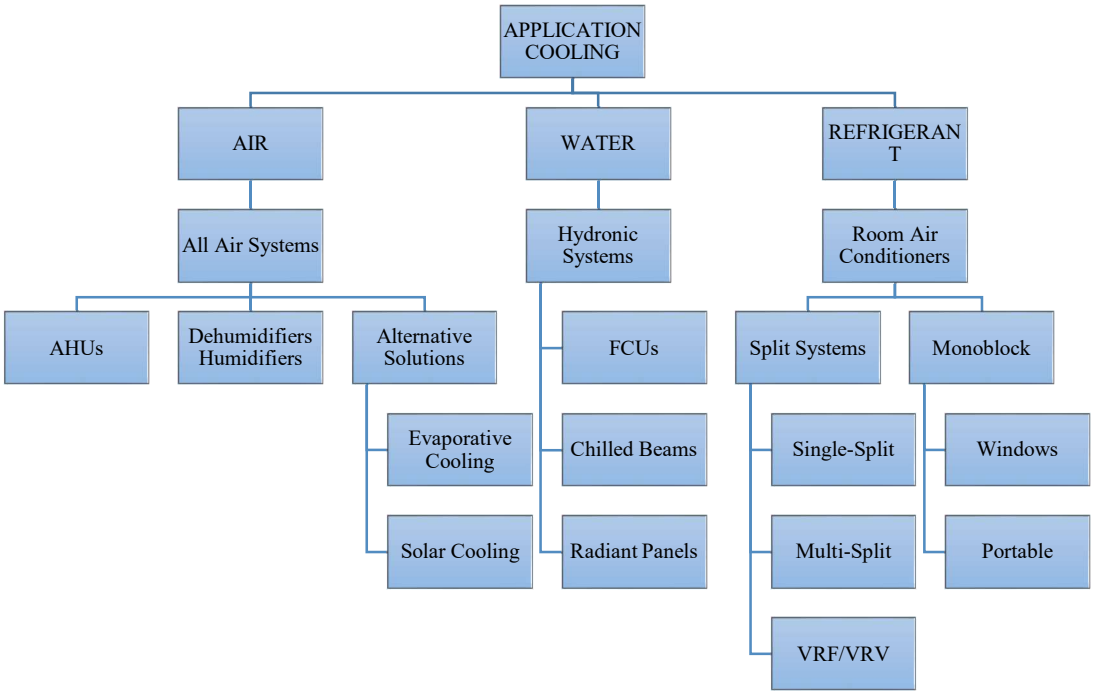


Figure 3 – Classification of Cooling Application

5.1 Heat Pump - Chiller

The heat pump is a device that provides heating or cooling effect from a natural source, which should be air, water or the ground. The system operates according to vapour-compression refrigeration cycle, thanks to which heat moves from a cold spot to a warm one. There are two configurations of the machine: heat pump for heating and chiller for cooling. Nevertheless, literature is used to call both the arrangements as heat pump solutions. It is useful, therefore, to highlight that single devices, which provide both heating and cooling effect, are available on the market; in this case, we speak about reversible heat pumps.

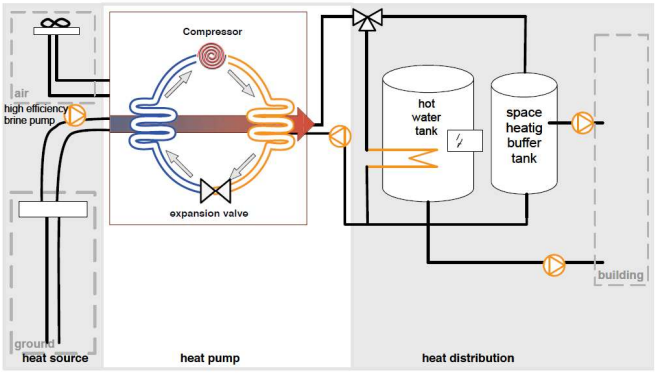


Figure 4 – Heat Pump Scheme (Source: European Heat Pump Market and Statistics 2013)

The European Directive 2009/28/CE (RES Directive) recognizes aerothermal, geothermal, hydrothermal fonts as sources of renewable energy and this is the reason why currently heat pumps are considered as a renewable generator of power for space heating and cooling. According to the normative, if the heat captured by a heat pump exceed significantly the energy consumed, it could be evaluated as renewable[6]. Inside the product, there is a refrigerant[7], which has the task to exchange thermal energy with the sources mentioned, as well as with the indoor carrier fluid, that is air or water. Therefore, there are many configurations, the most important of which are air/air, air-to-water and ground source heat pumps.

Taking into account what explained, it is necessary to inform that, in the present study, it has been decided to consider under the terminology *heat pump* configurations that deal with ATW (air-to-water) and GSHP (ground source) solutions, as well as thermally driven products,

[6] Heat pumps are considered as renewable generators if they fulfil RES directive's criteria, that is a minimum SPF of 2.6

[7] The refrigerant is a fluid with low evaporation temperature

since the split technology is identified by its own as a particular ATA equipment. In all former cases, the system transfers thermal energy to water in order to provide space heating and cooling, as well as in some cases DHW too. It means that all of them cover the opportunity to be alternative generators for several hydronic distribution systems, as radiant panels, FCUs and low-temperature radiators. A heat pump operates in better conditions when applied to low temperature final elements, because the product guarantees better performances when the difference between condensation and evaporation's temperatures is small; specifically, the efficiency increases as the temperature difference decrease. Hence, distribution systems that operate with fluid's temperature close to the ambient one reduce the gap with the outdoor unit's one. This aspect is fundamental due to the big energy saving potential related to the solution mentioned. On one hand, low temperature final elements, like radiant panels, allow to reduce water temperature supplied and so energy consumption due to heating source; on the other hand, heat pump represents a renewable and energy saving heating generator. Thanks to high coefficients of performance, currently around COP 3 and COP 4, they reduce energy consumption compared to conventional heating solutions in many circumstances. Furthermore, heat pumps are suitable for interacting with solar energy; one might imagine both a heat pump driven by PV's electricity[8], and the arrangement of the same with thermal solar panels in order to fulfil space heating and DHW requirements. Another positive aspect is related to the energy saving that the product provides;

A number of innovations are improving heat pumps, but two of these are fundamental. First, the conversion from standard compressor, which can only operate at full capacity, to variable speed motors has allowed heat pumps to operate close to heating and cooling capacity needed at any particular moment. This is possible thanks to an inverter, which controls the speed of the compressor and so the refrigerant flow, in order to regulate the room's temperature. Specifically, the heat pump chills internal rooms quickly and, once reached the indoor desired temperature, the product starts to work regulating the compressor velocity in order to maintain temperature supplied stable. By doing so, the system reduces electrical consumptions. On the contrary, traditional heat pumps regulated the indoor temperature by a periodical maximum load (ON)-switched off (OFF) operation of the compressor. Together with the reduction of energy consumption, the inverter technology have led heat pumps to achieve better performances also in terms of comfort quality by limiting fluctuations of temperature supplied. Moreover, this innovation has also minimizes the noise from the blower running at full speed.

[8] Heat pumps driven by renewable electric power represent a hundred-percent emission-free system

	Standard component	Highly efficient/ Improved component
Compressor	Standard compressor	Optimized compressor for heat pump application
Valves	Mechanical expansion valve	Electronic expansion valve
Heat exchanger: evaporator	Standard brazed plate HE	Micro-channel HE large evaporator surface
Heat exchanger: condenser	(Brazed) plate heat exchanger	Micro-channel heat exchanger
Circulators ("pumps")	Standard pump	High efficiency pump
Controls	Simple controls	Adaptive controls, connection to house grid, Internet
Fans and motors	Standard fan	Optimized blade, high efficiency motor
Refrigerant	R410a, R407c dominate	Reduced refrigerant charge, low GWP refrigerant (parallel work on efficiency improvements necessary)
Storage tank (External to the unit, but equally important)	Storage tank optimized for the heating demand of the building, different solutions for insulation	Optimized insulation, storage solutions optimized for larger share of RES integration in smart grids
Heat distribution	Floor/wall heating, fan coil units, standard radiators	Low temperature heating radiators, mini-hydronic heating with fan coils, more energy efficient fan coil units

Figure 5 – Standard and High Efficiency Components Heat Pump (Source: European Heat Pump Market and Statistics 2013)

The second advance for heat pumps concerns the scroll compressor, which consists of two spiral shaped scrolls. One remains stationary, while the other orbits around it, compressing the refrigerant by forcing the same into increasingly smaller areas. Compared to traditional compressors, the scroll configuration is smaller, has a longer operating life and is quieter. Furthermore, it ensures higher performances if compared to the reciprocating version.

In addition to these two main innovations, manufactures are also developing the technology from the refrigerant point of view. The F-Gas regulation has imposed limits on fluid's GWP values used for heat pumps; this is the reason why companies are looking for some alternatives to traditional R410a and R407c, which have to answer to economic and performance's requisites. Nevertheless, the present study does not think that the regulation mentioned would create huge problematics since the time granted to manufactures is enough to meet the regulation's requirements. For instance, Daikin is promoting a new ATW heat pump (*EcoCute*) that works with CO_2, as well as a new split product (*Ururu Sarara)* operating with R32.

Since current performances are still far from the ideal Carnot coefficient, there are still several rooms of improvement for heat pumps. Now it is difficult to predict other innovations concerning controls and compression, but some alternatives on the outdoor side are probable. For instance, handling the external air before using the same for evaporating/condensing the

refrigerant should be a new solution. If some water evaporates into the external air during summer, the temperature of the latter will decrease, as well as the temperature difference between the same and the indoor one. Hence, the heat pump can operate with higher efficiencies. On the contrary, if one imagines preheating the external air with some heat waste in winter, the difference between the evaporation and condensation temperatures declines and the performance of the system will increase. In addition, another probable solution deals with the heat recovery from the refrigerant in cooling mode (for example for heating water) instead of rejecting the same into the external air.

As one should recognize, the present chapter has given many attentions to heat pumps as reversible products instead of systems for only cooling purpose (chillers). This choice is the consequence of the fact that the diffusion of such technology is expected to be strongly correlated to the success gained as combined system, able to provide both heating and cooling. Especially in the residential sector, considering a combination of boiler and chiller would be not winning because of higher costs than installing just one element for hydronic heating and cooling. This consideration is confirmed also by the market trend, which is registering an increasing demand of reversible equipment instead of only cooling elements.

5.1.1 AIR-TO-WATER HEAT PUMP

ATW heat pump uses the external air as a source or a sink, respectively for the operation during winter or summer. Specifically, the air is identified as a low-enthalpy heat source since it is possible to extract heat power from the same by providing a refrigerant fluid at a temperature lower to the external one. The refrigerant, then, exchanges the same with the hydronic distribution system, which supplies the heating effect to all indoor rooms. On the contrary, during summer, the heat is extracted from the house by the same hydronic emitters and it is then rejected to the extern. When properly installed, the ATW heat pump can deliver three/four times more heat energy than the electrical energy it consumes. Nevertheless, the primary problem is exactly connected to the air source. The air temperature is variable through the day and this should have some negative impact on the product's performance. These difficulties are emphasized especially during winter; lesser is the outdoor temperature, higher is the difference between the source and the sink and, therefore, the performance of the system decreases. In other words, when the outdoor temperature declines under a certain threshold (usually around -10°C), the heat pump is not able to provide water to a sufficient temperature to achieve the total heating demand. This is the reason why, in colder regions, ATW heat

pumps are used together with other traditional heating systems, as boilers or direct electrical heating plants. Hence, there are still present some technological limits in the heating mode since the product is not suitable to climatic areas characterized by rigid temperatures. On the contrary, summer operation does not present any difficulties.

Another negative aspect is connected to the installation. If the procedure is very simple and the plant in not so much invasive for the indoor house volume, the outdoor units is subject to some critics due to position and noise. First, it is important to install the same away from windows and adjacent buildings in order to avoid complaints because of noise. On the other hand, the outdoor unit degrade the aesthetic of the façade and this is why installers try to applicate the same in strategic positions, which are not visible. This is in some way easier in multi-family buildings than in single-family houses. For the former, it would be more appropriate to have only one centralized generator, installed on the roof of the apartment block. ATWs are mainly suitable for new applications, but they should be used also for replacement of traditional heating systems. However, the ATW might be not adaptable to provide hot water to old radiators, and this is why the generator is always applied with suitable final emitters.

An important aspect deals with the cost of ATW heat pumps. As previously mentioned, the generator is in many cases matched with radiant panels, FCUs or low-temperature radiators and it covers a significant share in terms of investment. Generically, the price for a 20 kW product is around 8000-9000€[9], suitable for a multi-family buildings. It is evident that the generator has a deep impact on the global system's investment and this could have several negative consequence on the success of the same. This is the reason why, manufactures are trying to reduce end-user costs in order to make the same more competitive on the market.

From a technological point of view, manufactures are developing products through several directions. The most evident one is related to the evolution of hybrid ATW heat pumps that also use a conventional boiler when outdoor temperatures are very slow. One of the most important limit is connected to the temperature range adaptability, aspect on which many manufactures are working on. For example, they are improving some heat pumps configurations that guarantee the same level of operating efficiency also with outdoor temperatures down to -20°C. At the same time, in order to facilitate the diffusion in the heating market, an increasing number of heat pumps with two compressors are designed to reach up to 65°C in order to more easily replace existing boilers. This has led ATW heat pumps to expand their market also in the renovation segment, where medium temperature radiators (45°C-55°C) are employed. However, simply exchanging the existing boiler with a heat pump,

[9] A reversible heat pump's price is 10% more expensive than a chiller's cost

mainly when connected to high temperature distribution systems (65°C and more) in currently not recommended[10].

In addition, many manufactures are also working on the realization of low-capacity products, which are suitable for small habitations, as well as for low-energy buildings. Another important target concerns the improvement of the technology's performance, for which there are said to be many rooms of improvement. For instance, the combination of heat pumps and evaporative cooling is supposed to rise the summer performance coefficient, by reducing the temperature's difference between evaporator and condenser[11].

All-in-one heat pump systems that combined functions such as heating, cooling and DHW, integrated to thermal solar panels, have been developed thanks to advance controllers. Many manufactures are promoting the combination of reversible heat pumps with solar-thermal collectors or PV panels.

DAIKIN ALTHERMA

Figure 6 – Low Temperature Heat Pump (Source: Daikin Altherma Installer Catalogue)

- The product uses a range of efficient compressors, limiting electrical inputs to its maximum, that is to say the compressor is designed to work at optimal frequencies, delivering the low capacities needed by houses with low heat loads. In addition, Dainking Altherma optimizes efficiency at all outside and water temperatures with the use of:

    - A pressure sensor for detailed measurement of condensing pressure level to evaluate the optimal amount of subcool;
    - An individual dimensioned plate heat exchanger per capacity class, to offer optimal efficiencies per capacity range.

[10] European Heat Pump Market and Statistics REPORT, 2013
[11] The outdoor air is chilled by a water spray, before the former is used for condensing the refrigerant

- Daikin Altherma maintains its high heating capacities down to low outdoor temperatures (equilibrium temperature at -10°C), thanks to optimized controls to achieve higher frequency of use at low outdoor temperatures and perfectly dimensioned plate heat exchanger to maximize the heat exchange surface.

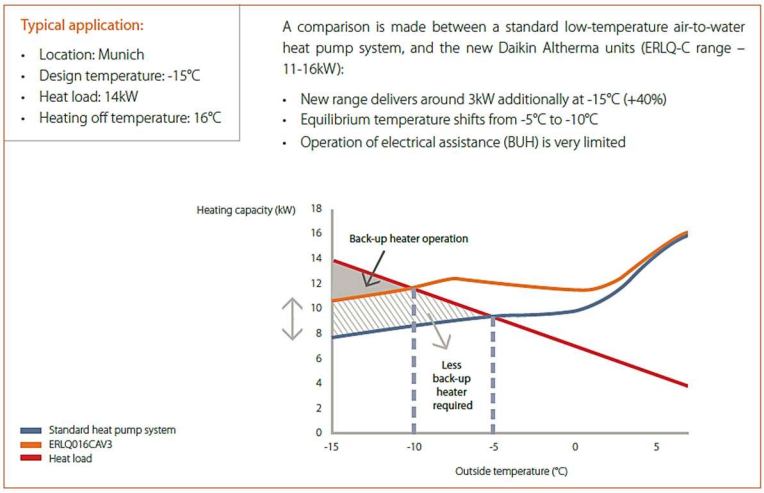


Figure 7 – Heating Capacity- Outside Temperature (Source: Daikin Altherma Installer Catalogue)

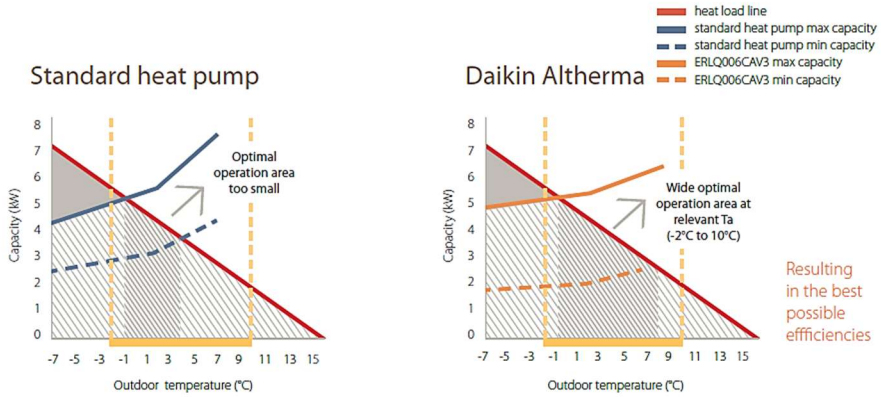


Figure 8 – Standard HP vs Daikin Altherma (Source: Daikin Altherma Installer Catalogue)

- The product ensures minimum energy consumptions thanks to Daikin inverter compressor with high modulating range. In other words, the compressor can turn in partial load operation in order to achieve:

    - Higher compressor efficiency in partial load
    - Delivered capacity exactly matching the actual heating demand of the building

- Obtaining the capacities needed with the minimum energy consumption
- Less on/off operation

- The combination between the inverter compressor and the weather-dependent set-point control guarantees maximum efficiency at each outdoor temperature, assuring stable and low as possible room temperatures. This results in:

  - Higher heat pump efficiency
  - No unnecessary overheating
  - Continuous heating at low water temperature providing stable room temperatures

Figure 9 – ATW with UFH (Source: Daikin Altherma Installer Catalogue)

- Optimal use of energy limiting electrical inputs of auxiliary components.

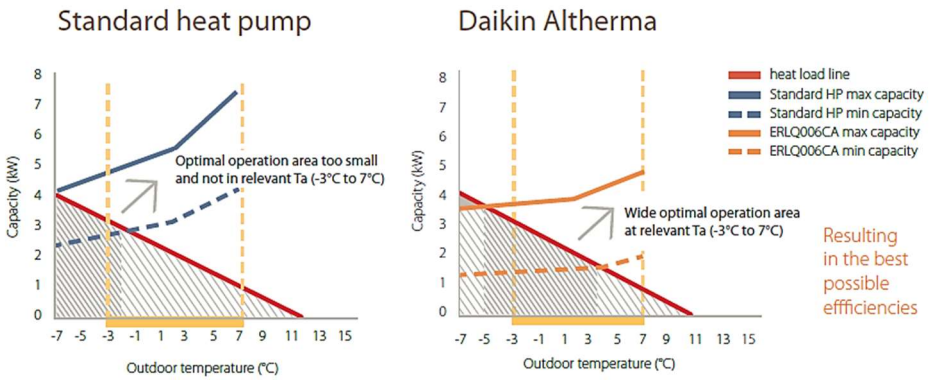


Figure 10 – Standard ATW vs Daikin Altherma (Source: Daikin Altherma Installer Catalogue)

- Daikin Altherma is designed to meet the requirements of newly built and low-energy houses characterized by low heat load (low capacity unit of 4 kW). Low capacity product are able to fulfil the new-build house market in Europe, which is moving towards smaller heat loads, due to growing importance of

energy saving, strengthened legislation as EPBD, decreasing of new-build houses and 20-20-20 targets.

- Only one outdoor unit is able to provide heating and cooling, using the same emitters for both the effects. Furthermore, Daikin Altherma has a large operation temperature range (up to 55°C), so that it can be connected to all types of low-temperature heat emitters as UFH (25°C-35°C), heat pump convectors (35°C-45°C) and low-temperature radiators (40°C-55°C).

- Daikin offers different integrated indoor unit, including compact installations when DHW is required, as products suitable for thermal solar panels' connection.

Figure 11 – Daikin Altherma with PVs (Source: Daikin Altherma Installer Catalogue)

5.1.2 GROUND SOURCE HEAT PUMP

The geothermal energy can be indicated as the heat present in the ground, which is quite constant during the whole year in terms of quantity and temperature level. The geothermal heat pump exchanges heat with the ground, through probes that are installed in well or horizontal excavations[12]. This product can operate for both heating and cooling since the ground temperature, at a certain depth, is higher that the outdoor one in winter and at the same time it is lower than the latter in summer. The benefit concerning the ground is identified in the stability of source's temperature[13] and, hence, the optimal performances that are registered during the whole year. The constancy of the ground temperature makes the

[12] There are three kinds of probes: vertical, horizontal and energetic pole
[13] It has been observed that, at 10m of depth, the ground temperature varies of just 1°C during the whole year, which is more or less negligible

difference between the same and the indoor temperature stable in both heating and cooling seasons. Therefore, no problematics because of source's temperature are recorded. A geothermal heat pump is always install in order to fulfil both seasonal energy demands because, by doing so, the system avoids to create damages to the ground. Furthermore, this solution leads to energy and money saving, because it is demonstrated that a GSHP allows energy consumptions 50% lower than the ones consumed by a traditional equipment made by a boiler and a split air conditioner.

Although GSHP are a mature technology that guarantees great performances for space heating and cooling, it has experienced a difficult progress in the market due to some aspects. For sure, the two most important ones concern with high costs and installation's complications. Indeed, the system needs big spaces for installation, whether probes are horizontal or vertical and, therefore, the realization of the same are limited to just some suitable areas. On the other side, the realization of wells and excavations is very expensive and this is a factor with a deep influence on households' choice, even if they generically do not require any maintenances. Hence, such technology has been applied in the residential sector mainly in Scandinavian Countries, where space and money availability makes the same to be an affordable alternative. However, manufactures and governments are promoting GSHPs, making them more attractive thanks to incentives' scheme. Currently investment costs are from 800 to 1600/1700 €/kW but, because of national subsidies, they are reducing further. In particular, ground source heat pumps should become a more charming solution for some multi-unit edifices. However, one should consider that providing thermal power to a multi-unit user results in excessive length of geothermal probes, which can be a problem especially for costs and installation procedure, more than a matter of space. Nonetheless, some great benefits, including economic ones, are possible in case of low-energy multi-family buildings.

geoTHERM EXCLUSIVE – VAILLANT

GeoTHERM exclusive offers a complete solution for house comfort providing heat in winter, 'passive' cooling in summer and DHW throughout the year, all from a single unit. The cooling operation is defined as passive since the excess heat in the living space is withdrawn via the underfloor heating system and then transferred to the ground. There are three different output models, that is to say 6kW, 8kW and 10kW. According to Vaillant technical data, the product supplies a water maximum temperature of 62°C for DHW and a minimum one of 25°C; the system is equipped with an electric auxiliary backup heater. GeoTHERM can be connected to a suitable high performance hot water cylinder for domestic hot water and to an

underfloor heating or radiator system for space heating. However, since the scope of the present study concerns the cooling mode, radiant panels are the final emitters that match better with the ground source heat pump.

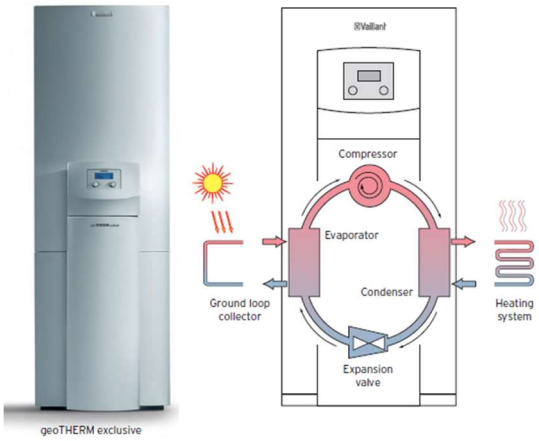


Figure 12 – Vaillant GeoTHERM Exclusive (Source: Vaillant)

5.1.3 THERMALLY DRIVEN HEAT PUMP

Thermally driven heat pumps are generically recognized in absorption and adsorption arrangements. The present chapter considers also the gas-driven products as a particular configuration in such category. TDHPs (thermally driven heat pumps) work at three temperature levels:

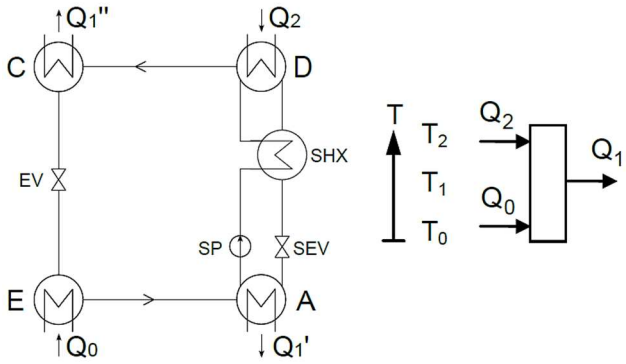


Figure 13 – Thermally Driven Heat Pumps (Source: Thermally driven heat pumps for heating and cooling)

- Driving heat Q_2 is supplied at a high temperature level;
- Useful cool (cooling operation) or low temperature heat (heating operation) Q_0 is supplied at low temperature level;

- Q_l is the useful heat released at a medium temperature in heating mode, while it is rejected to the extern in cooling operation;

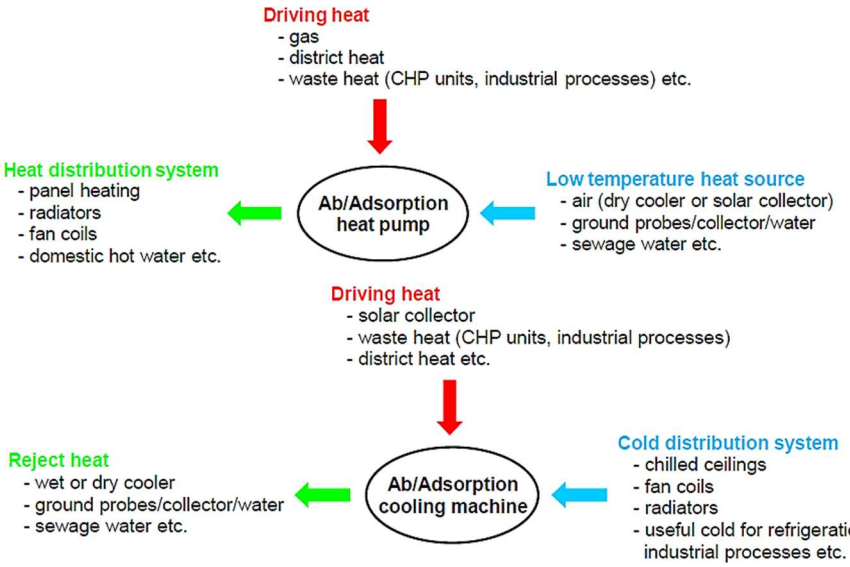


Figure 14 – Absorpion and Adsorpion Heat Pumps (Source: Thermally driven heat pumps for heating and cooling)

Thermally driven heat pumps are currently a small yet emerging segment also for residential applications, especially for their adaptability to high temperature existing heating systems. The most emphasized aspect is that the driving thermal power comes from wasted heat or, in particular, from renewable sources, as the solar one. The heat released by a thermally driven heat pump is used to provide room heating or DHW with a temperature level up to 70°C. On the contrary, the low temperatures provided by the same system ranges from 6°C to 18°C for air conditioning. In cooling mode, driving thermal power is preferably provided by solar or waste heat, with a temperature range from 55°C for solar cooling up to 95°C for district heat. Higher driving temperatures, over 120°C, are used for more advanced cycles, for example double-effect ones. Another special feature deals with the fact that such heat pumps can offer cooling and heating simultaneously, even if in most cases the mentioned demands do not occur at the same time. The technology is developing toward better performances, capacity's reduction to residential scale, more compact systems and intelligent integration with other heat sources. The most promising configurations for domestic use concerns heat pumps driven by gas or by solar thermal power. On one hand, the former propose could represent an attractive more efficient alternative to traditional boiler, especially in the European areas strongly based on gas fuel; high investment costs and dimensions, as well as the non-awareness of the system would be the main factors that might influence negatively the future success of the same. On the other hand, there is a strong tendency to combine heating

generators and solar panels in order to fulfil thermal energy demands. The combination between absorption heat pumps and solar thermal collectors is another interesting configuration for both space heating and cooling. However, some simulations and tests are needed. Nonetheless, since currently the capacity scale is quite high, thermally driven heat pump should represent a good alternative as centralized generator for multi-family edifices.

Academic researchers are mainly focus on adsorption solutions since they have still potential of progress and performance's optimization; on the contrary, absorption is a mature technology. Both systems are currently developing in order to increase the energy density and to decrease production costs.

5.1.3.1 ABSORPTION HEAT PUMP

The principal difference between a traditional heat pump and an absorption one deals with the present of a pump instead of a compressor, in order to overcome the pressure difference. Hence, the refrigerant is not compressed as a vapour but is pumped in a liquid state. The electrical input required is very small due to the considerably lower specific volume of liquid compared to vapour refrigerant.

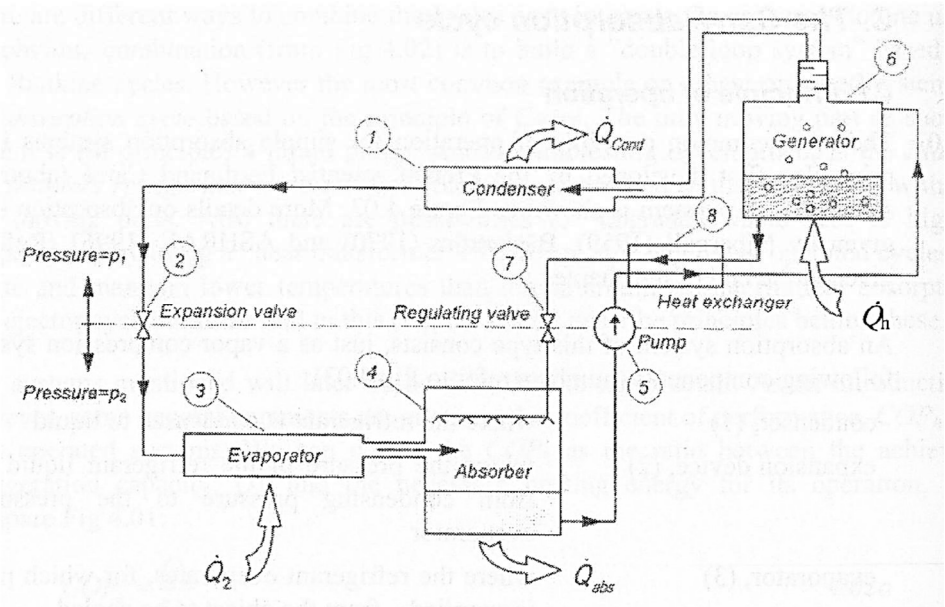


Figure 15 - Absorption Heat Pump (Source: Padua University Documents)

A part from the heat released in the condenser, some is generated also in the absorber and has to be rejected. Therefore, the ratio between the useful heat Q_1 and the heat from the low temperature source Q_0 is larger than in compression heat pumps. Thermally driven heat

pumps can be applied to traditional radiators, since the temperature of hot water is too high for other emitters. When operating in cooling mode, an absorption heat pump can supply chilled water for different kinds of distribution systems, AHUs, FCUs or radiant panels. The heat source is classified according to the temperature level; literature talks about low temperature's source or single effect machine on one side, and on the other side about a double effect system with higher temperature's source[14]. Multi effect cycles are used to increase the efficiency (COP)

Two working pairs prevail for absorption heat pumps and cooling machine: water/LiBr and ammonia/water. Both of them have positive and negative features.

- Water/LiBr permits the highest energetic and economic efficiency using simple, well-engineered, and relative compact systems. Water has high latent heat and it is non-toxic; unfavourable phenomenon is the formation of crystals at high absorbent concentration. Water/LiBr heat pumps have been produced and operated in large numbers; hence, they are a mature technology.
- Ammonia is toxic, flammable and explosive in air for some concentrations; the solution water/ammonia does not crystallize. These systems are more complex, not efficient as the ones above and need more auxiliary power. They can be operated with environmental heat sources as air or ground. Market available ammonia/water products supply DHW up to 70°C.

Indices	Cooling temp: 5–10 °C		
Effect	Single	Double	Triple
Heat source temp. (°C)	80–120	120–170	200–230
Cooling capacity (kW)	35–7000	20–11,630	530–1400
Thermal COP	0.5–0.7	1.0–1.2	1.4–1.7
Current status	Commercial	Commercial	Experimental and small batch commercial
Remark	1. Simplest and widely use 2. Using water as a refrigerant 3. Negative system pressure 4. Water cooled absorber is required to prevent crystallization at high concentration	1. High performance cycle 2. Heat of condensation from the first effect is used as heat input for the second stage 3. Using water as a refrigerant 4. Negative system pressure 5. Water cooled absorber is required to prevent crystallization at high concentration	1. High complexity control system 2. Likely to be direct fired as the input temp. is high 3. Require more maintenance as a result of high corrosion due to high operating temperature 4. Using water as a refrigerant 5. Negative system pressure 6. Water cooled absorber is required to prevent crystallization at high concentration

Figure 16 - Characteristics of Water/LiBr Cycle (Source: Padua University Documents)

5.1.3.2 ADSORPION HEAT PUMP

In the adsorption configuration, the refrigerant is absorbed in pores of a solid sorbent, which has to be porous and with high internal surface. The most common working pairs are

[14] Single effect cycle: T<120°C with COP = 0.6-0.8; double effect cycle: T>170°C with COP = 1-1.2

water/silica gel, water/zeolite, ammonia/activated carbon and methanol/activated carbon. One negative aspect concerns the fact that over the time the adsorption capability decreases. An adsorption heat pump does not have any moving component like pumps, but its operating process is discontinuous and this is why the technology is evolved into so-called two reactors, which are usually used and operated in counter-phase. Refrigerant machines using an adsorption cycle can be driven by sources with lower temperatures, around 55-65°C.

Adsorbent and refrigerant		Heat of adsorption ($kJ\,kg^{-1}$)	Toxicity	Generation temp. (°C)	Heat sources	Applications
Silica gel	H_2O	2800	No	60–90	Low temperature waste heat, solar energy	Space cooling, refrigeration
	CH_3OH	1000–1500	Yes			
Zeolite	H_2O	3300–4200	No	>150	High temperature waste heat	Space cooling, refrigeration
	NH_3	4000–6000	Yes			
Activated charcoal	C_2H_5OH	1200–1400	No	80	Low temperature waste heat, solar energy	Low temperature, ice making
	CH_3OH	1800–2000	Yes	80		
$CaCl_2$	NH_3	1368	Yes	95–120	Low temperature waste heat, solar energy	Low temperature, ice making
	CH_3OH	N/A	Yes			

Figure 17 – Characteristics of Working Fluids (Source: Padua University Documents)

The efficiency of adsorption configuration is lower if compared to the absorption one and the discontinuous working process involves fluctuating outlet temperatures of the hydraulic circuits. Even if they seems to more compact to lower capacities, the absorption version is currently preferred.

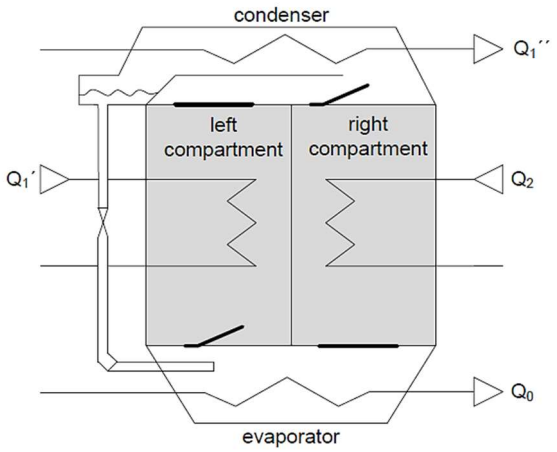


Figure 18 – Adsorption Heat Pump (Source: Thermally driven heat pumps for heating and cooling)

5.1.3.3 GAS-DRIVEN HEAT PUMP - GHP

The GHP is a heat pump in which the driving heat for the operation of the same comes from gas combustion. Theoretically, the operation of such machines is not different from the ones described above for absorption and adsorption configurations; simply, the GHP is a

precise arrangement of the same by indicating the driving heat source. The working scheme of an absorption gas-driven heat pump process should be represented as in Figure 19.

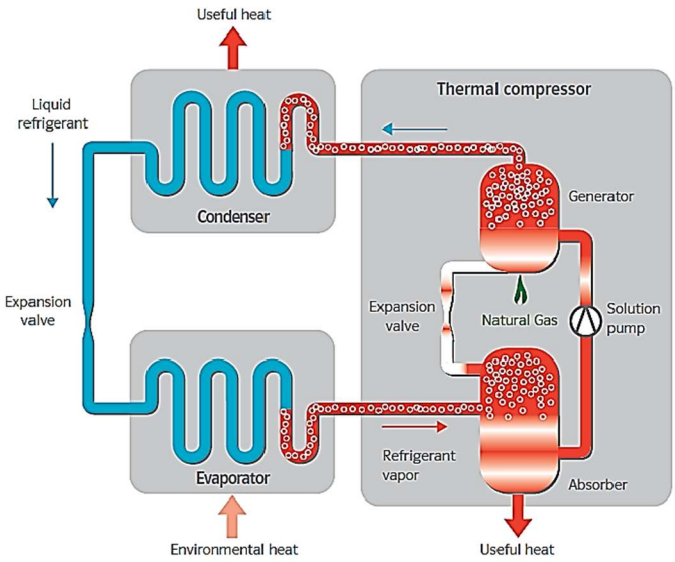
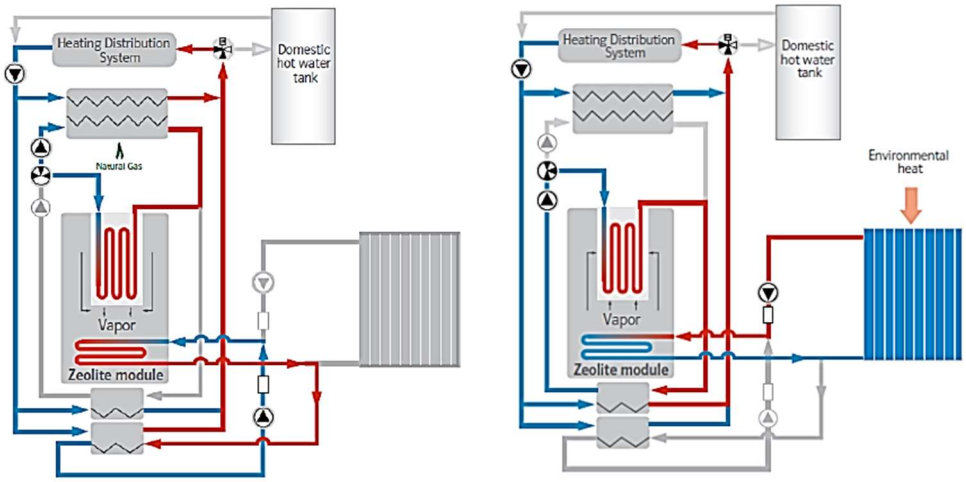


Figure 19 – Gas-driven Heat Pump (Source: Thermally driven heat pumps for heating and cooling)



Vaillant gas-driven heat pump during the desorption phase (left) and the adsorption phase (right)

Figure 20 – Vaillant Gas-driven Heat Pump

According to *Thermally driven heat pumps for heating and cooling*, some manufactures are developing hybrid systems that combine the adsorption technology with the gas-fuel source, as well as the solar energy. It is, for instance, the case of Vaillant and Viessmann companies, which are promoting hybrid-heating appliances that integrate the adsorption cycle with a gas condensing boiler. Figure 20 shows the Vaillant GHP, in both operation of desorption and adsorption. In the lefts side, the zeolite is heated up by a hot water

loop connected to the adsorber heat exchanger with the gas burned heat exchanger. The water vapour condenses on the lower heat exchanger, delivering the useful load to the heating distribution system. When a certain desorption end temperature is reached, the boiler is switched off and the absorber heat is transferred to the heating distribution system, reducing so the temperature of the zeolite. The cold and dried zeolite then absorbs water vapour from the condenser, reducing its temperature until it is lower than the temperature of the brine coming from the solar collector panel. From then on, the lower heat exchanger works as an evaporator, feeding ambient heat into the process.

One positive aspect of gas-driven heat pump[15] is correlated to the fact that the use of ambient heat is lower than the one required by a vapour compressor heat pump of the same heating capacity and same seasonal performance factor. This means that GHPs have cost benefits concerning the ambient heat source[16].

Gas driven heat pumps might gain an important role in the next fifteen years for residential space heating and cooling. The necessity to improve buildings energy performance has led until now to develop at the same time products that should use conventional fuels more efficiently or that are combustion-free. One can recognize in the first category modern condensing boilers, which has been promoted as alternatives of old high-temperature non-condensing heating generators. Hence, the gas-driven heat pump represents an intermediate configuration between tradition and innovation, since the machine integrates the use of fuel and ambient energy. As done by condensing boilers, GHPs are supposed to play a quite significant role in the market as solutions that matches the characteristics of the European gas-based heating scheme as well as the necessity to increment the penetration of renewable sources in the same. A fundamental aspect concerns the fact that such technology can provide both heating and cooling effect. Given actual costs, dimension and capacities, GHPs can be installed mainly in centralized multi-family systems, both for new buildings and replacements of old generators. A perfected setting is reached by combining GHP and FCUs, in order to install only one equipment able to fulfil seasonal loads. The evolution toward small-scale products will ensure to this technology a probable success also for single-family applications.

[15] This positive aspect is confirmed for each kinds of thermally driven heat pump

[16] Here the example given by *Thermally driven heat pump for heating and cooling*. It is supposed to have a vapour compression heat pump with a rated capacity of 8kW; if the SPF equals 4, the amount of electricity and ambient energy is respectively 2kW and 6kW. If one assumes an average power station efficiency of 38.5% for the production of the electrical power used, the global SPF becomes 1.54 based on primary energy consumption. On the other side, with a gas-driven heat pump with same heating capacity and SPF, the energy coming from gas is 5.2kW and the ambient one is 2.8kW. Therefore, the ambient heat required by a GHP is less than 50% of that the one used in a vapour compression heat pump; "this gives a cost benefit concerning the ambient heat source in favour of gas-driven sorption heat pumps.

5.2 Hydronic Cooling Systems

In the previous chapter, chillers and reversible heat pumps have been examined as generators of hydronic cooling systems that, therefore, include inside themselves distribution plants and final emitters. When speaking about an hydronic cooling plant it is used to consider distribution elements which are suitable for both space heating and cooling; for instance, FCUs are devices that can provide thermal power both in winter and in summer, whether they are connected to a boiler and a chiller or to a reversible heat pump. On the contrary, when the focus is on hydronic heating systems it is more probable that emitters are just for that purpose, for example traditional radiators. In the following pages, the study develops an analysis of the most important hydronic emitters, highlighting suitable generators, installations, as well as pros and cons.

Generator	*Emitters*
Chiller or reversible heat pump	Fan coil units Chilled beams Radiant panels

Table 2 – Hydronic Generator and Emitters

5.2.1 FAN COIL UNITS

Fan coil units are final emitters, part of a hydronic cooling system driven by a chiller or a reversible heat pump. Fan coil units are simple devices consisting in two main elements, that is to say a coil for the heating/cooling purpose and a fan. The fan produces forced convection across the heat exchanger, in which chilled or heated water circulates. The temperature of the same is from 7°C to 12°C in cooling mode and around 50°C in the cool season. Furthermore, the majority of the same are equipped with filters in order to control the air cleanliness. Hence, several types of configurations exist; first, there is a basic subdivision between two-pipe or four-pipe fan coil units.

- *Two-pipe fan coil units*: they have one supply and one return pipe. These transmit hot or cold water according to the conditioning demand.

- *Four-pipe fan coil units*: they have two supply pipes and two return pipes. This configuration guarantees that cold and hot water can enter the fan coil at any time, since one supply pipe is connected to the heat generator, while the other one to the chiller. In this way, the system is able to provide

contemporarily heat and cool in different areas of the building. This is the reason why the four-pipe arrangement is most common applied.

However, the most important subdivision is based on the comfort level fan coil units can provide in terms of temperature, humidity and air quality. In particular, most common residential applications do not achieve the humidity control besides any fan coil unit is equipped with a drain pan for condensate. Fan coil units are installed within the rooms for the main purpose of temperature control by recirculating indoor air through the heat exchanger. Specifically, the typical control system consists of a thermostat, multi speed fan, a heating/cooling coil with control valve. Individual zone thermostats are coupled to the fan speed controller and hydronic controls. Therefore, it is possible to obtain high level of individual control for the air temperature; according to personal preferences, the operation of emitters can be regulated in each room or at least interrupted. Regarding the humidity rate, a certain amount of water is effectively condensed and collected with the drain pan, but no precise control is available on the same.

The traditional scheme of a fan coil unit is recognizable in Figure 21, in both arrangements vertical and horizontal. It is recognizable that the structure of the same is very easy, so that the removal and maintenance of single parts is not difficult and expensive. Fan coil units may be concealed or exposed.

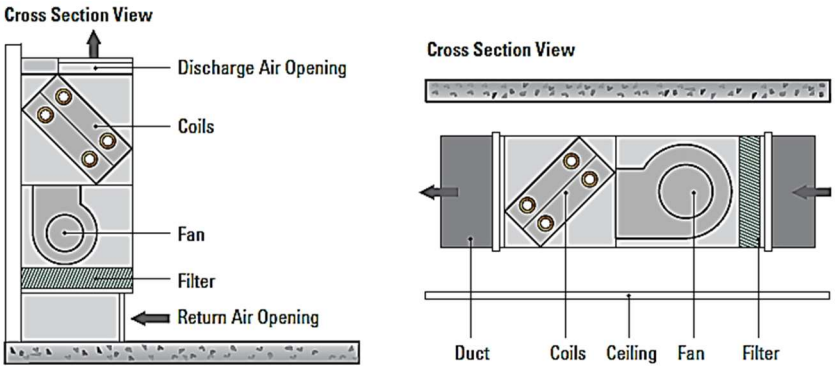


Figure 21 – Fan Coil Units (Source: Engineering Guide Fan & Blower Coils)

- Exposed units are installed in a visible position. They use insulated casings in order to reduce the amount of noise delivered and the dimensions of the same are reduced in order to minimize the amount of occupied space they require.

- Concealed units are installed generically in a ceiling plenum or a service zone. Therefore, the return air is taken from the room and sent to the fan coil unit through ductworks.

There are some plant's configurations that ensure also the treatment of the latent load of the primary air. These are:

- *Fan coils with dedicated outdoor air systems:*
  Fan coil units can be used with an air-handling unit. In this operation scheme, the external element AHU is supposed to dehumidify and condition the outdoor air, as well as to control the latent heat of the internal air. Fan coil units have the only task to achieve the sensible control of the latter. This solution has the advantage to ensure proper humidity control at each zone. Furthermore, the air replacement is guaranteed. Eventually, the AHU can be turned off and fan coils can operate in the traditional configuration. However, it is clear that this solution is quite complex and expensive.

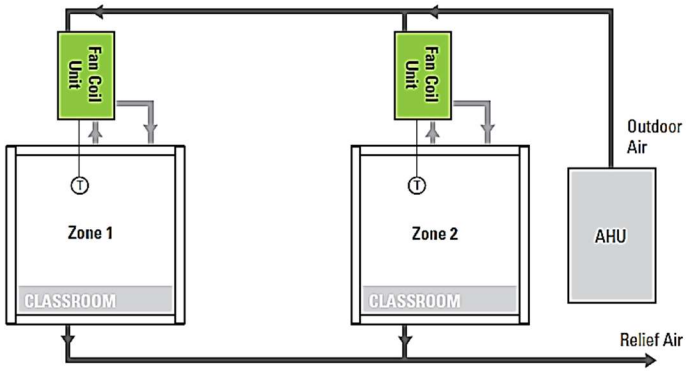


Figure 22 – FCUs with AHU (Source: Engineering Guide Fan & Blower Coils)

- *High performance fan coils:*
  High performance fan coils consist in an arrangement that guarantees better room temperature control and lower noise. This is reached by reducing the outlet air velocity thanks bigger ducts, which means that volume and costs of such solution are quite high. Generically, the system is furnished with also higher efficiency filters and coils and, in particular, the same is equipped with a drain pan in order to capture condensate. The fan coil is usually installed horizontally, far from main rooms.

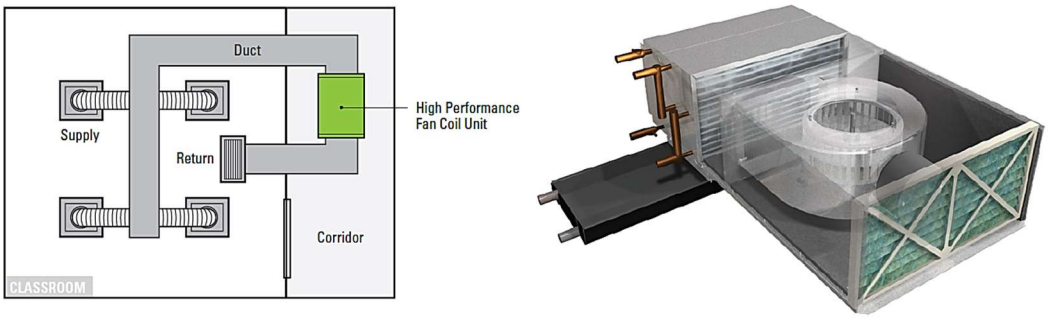


Figure 23 – High Performance Fan Coil (Source: Engineering Guide Fan & Blower Coils)

- *Blower coil units type:*

  A blower coil unit is a compact solution, usually for high cooling demand, between traditional fan coils and a central AHU. The system mixes outdoor air with the internal one and handle the same thanks to a filter and coils. In this way, the comfort is ensured in terms of temperature, humidity and air quality. Thanks to belt transmission, the fan can operate at different speeds; a blower unit can be used both for constant and variable air volume. A well-designed product should be compact, have low air and water pressure drop across the heat exchanger to reduce fan and pump power requirements, and provide good access to all of the unit's components in case of maintenance.

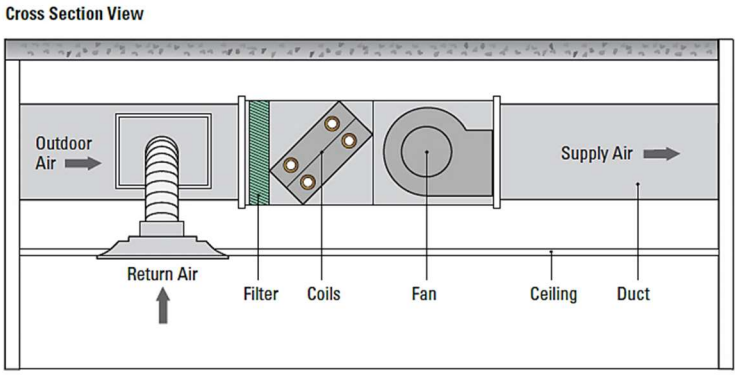


Figure 24 – Blower Coil Unit (Source: Engineering Guide Fan & Blower Coils)

As previously mentioned, it is useful to have an evaluation at 360° of the fan coils' technology in order to better comprehend benefits and disadvantages of the same. First, technically speaking, the comfort level achieved by fan coil units is not so fine. The system operates by controlling the indoor air in terms of quality, thanks to a filter, and temperature, by forcing the air to pass through the heat exchanger. The main problem concerns the air movement, since the flow of the same is not homogenous and therefore the room is not uniformly chilled. In many cases, the air comes from some emitters installed inside the room

and the temperature of the same is very lower if compared to the internal one. Hence, the ambient is more chilled in the areas that are closest to emitters; on the contrary, far from final elements the temperature might be not so comfortable. Another consequence of the forced cold airflow is related to the fact that some people should be not satisfied because of draughts of chilled air. Moreover, especially in the case of floor-standing fan coil units, the air comes back from the floor and it takes with it some dust. This is the reason why many manufactures are developing solution that ensure a better diffusion of the air inside chambers in order to guarantee a homogenous cooling of the same. In addition, fan coils realize condensation of the vapour but, generically, it is not possible to have a precise control of the same. Nevertheless, the technology has had a great success also in some humid countries, in particular in Italy. In the end, one should not forget that because of the fan and so the forced airflow there are some problematics concerning noise too. In order to avoid this bother, producers offer products together with insulated casings, although it is impossible to make them completely silent.

FCUs are always applied in order to provide both heating and cooling; there are almost no applications of such products designed just for one thermal effect. This is the reason why up to now FCUs have represented one of the main solution for reversible plant, in which the same final emitter is used in both cold and hot seasons. While generically in the single-family segment the scheme of air conditioning is divided between the one that supply space heating (boiler + radiators) and the one for cooling (split), FCUs are a technology that has been adopted principally in multi-family buildings, where centralized generators as boiler and chiller are installed. In reality, FCUs are not so used in the residential sector, but they are mainly suitable for big spaces and for applications where individual zone temperature control is required, as in hotels and office buildings. However, FCUs are a valid alternative for multi-unit edifices with centralized generator; they should be matched with the pair boiler/chiller or with a reversible heat pump. The advantage is related to the fact that same emitters are used during the whole year and they are suitable in order to meet households requisites, especially the ones related to the individual control.

Figure 25 - FCU Typologies (Source: Climaveneta)

The most common configuration applied in the domestic sector is the first one of Figure 25, that is to say a fan coil unit that can be installed in the wall. One can immediately recognized that the mentioned product is similar to a radiator. Indeed, FCUs are an optimal solution for multi-family buildings' renovation or refurbishment, in which radiators are substituted with such devices, moreover able to supply cooling. The great affinity between floor-standing FCUs and radiators, in terms of generators and positions, make the installation easy and not expensive[17].

5.2.2 CHILLED BEAMS

A chilled beam is a hydronic emitter for air heating and cooling. It consists in a heat exchanger that can be "either integrated into traditional suspended ceiling systems or suspended a short distance from the ceiling of a room"[18]; inside the beam, there are pipes of water, in both configuration of two or four pipes. The advantage of the four-pipe design is connected to the possibility to provide simultaneously cold and hot water in different rooms. Beside chilled beams use water as operative fluid as radiant panels do, there are precise dissimilarities between the same. In particular, the most important is that chilled beams are mainly based on convection than on radiation. Two categories of chilled beams are available; the classification depends on the comfort level achieved.

- *Passive beams:*

  Passive beams can only provide temperature control of a room by heating or cooling the indoor air. Therefore, the passive configuration does not satisfy requirements of humidity control, air quality and ventilation. The device consists in a coil through which cold or hot water passes in order to chill or heat the indoor air. The heat exchange creates a density difference between the air near the ceiling and the one far from the same; this gradient causes inducted air motions that are represented in the Figure 26. "This allows a passive chilled beam to provide space cooling without the use of a fan"[19]. On the contrary, the natural movement of the air is disadvantaged in heating mode since the convention is not sufficient for having a good distribution of the effect in the whole room. This is the reason why chilled beams are sometimes

[17] According to *ShopClima* the price of Climaveneta iLIFE fan coil is from 300€ to 500€
[18] Wikipedia – Chilled Beams
[19] Understanding Chilled Beam Systems

equipped with a fan in order to force the warm air to the ground. The passive system is very simple and not invasive; however, it is evident that many limits are still present for the cooling capacity and for the necessity of a fan for the heating operation.

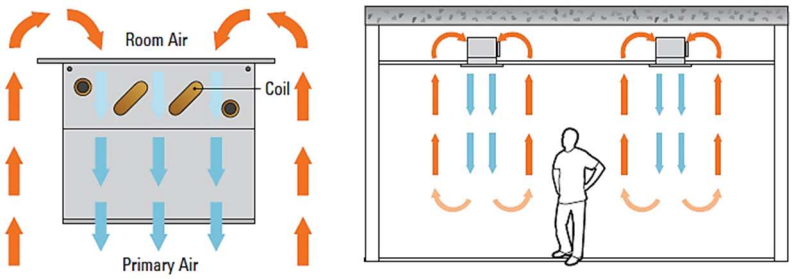


Figure 26 - Passive Chilled Beams (Source: Understanding Chilled Beam Systems)

- *Active beams:*

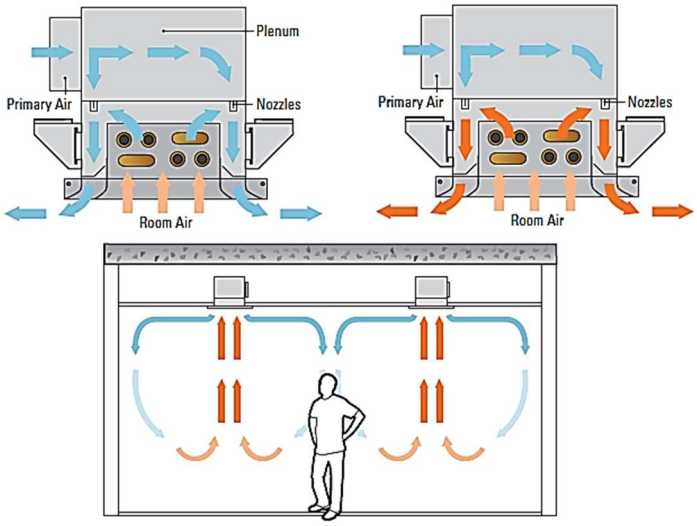


Figure 27 - Active Chilled Beams (Source: Understanding Chilled Beam Systems)

Active beams are connected to a centralized AHU. The latter takes the outdoor air and handles the same in terms of dehumidification-humidification and temperature control. The main target of the air-based site is to ensure ventilation requisites, as well as to control latent loads. In this way, the global system is able to satisfy all the comfort requirements and, in particular, to fulfil the combination of sensible and latent load. However, since both heating and cooling capacities of chilled beams are quite low, the AHU can give an addition support for the sensible loads. On the contrary, the contribution of

chilled beam is just to provide heating or cooling effects. Indeed, the primary air is forced through the coil and by flowing with high velocity it causes a reduction in the local static pressure, inducing room air through the heat exchanger; the airflow scheme is reported in Figure 27. The advantage of such combination, together with high comfort level achieved, is identifiable in a reduction of air ductworks' dimensions and AHU's size if compared to tradition all-air systems. Since chilled beams fulfil part of the cooling effect by chilling the inducted room air, the AHU has to handle a lower primary airflow. However, the global system result more invasive and expensive.

Evaluating chilled beam themselves, some other features emerge. First, both cooling and heating capacities are quite low[20] and this is the reason why installers apply the same in buildings with low cooling loads and in no-humid climates, as well as low air-change requisites. Nowadays, indeed, most common applications are for commercial edifices and offices. Another conclusion concerns with the fact that the airflow of active chilled beams might be unconformable and noisy too. Furthermore, since the indoor dew point must be maintained below the surface temperature of the chilled coil in order to prevent condensation, the water temperature in cooling mode is in the range 16°C-19°C. The water temperature is higher than the one of the cooled air used by an all-air cooling alternative and, hence, operating costs are lower. Nevertheless, if an AHU is included, the chiller has to provide cold water around 7°C to the same and no advantages are identifiable in this case in terms of operating costs. Therefore, taking all into consideration, the system's complexity, investment costs, noisiness and low comfort level achieved are the reason why the present study considers chilled beams as not suitable for residential applications. Even if manufactures are developing advanced products in which lighting, electrical wiring and sprinklers are incorporated, chilled beams seem to be more appropriate for the commercial sector instead of the domestic one.

Figure 28 - Frenger System (Source: Frenger)

[20] In the majority of cases, they are installed in combination with another separated heating system

5.2.3 RADIANT PANELS

Radiant panels, together with fan coil units, are a significant application speaking about hydronic cooling. They consist in a series of pipes that can be installed in the floor, ceiling or parietal walls and through which the system supplies hot or cold water to rooms. The pipes' material is generically plastic, because of its installation facility and predisposition of avoiding corrosion and scaling. The pipes are organized due to two configurations, a coil or a spiral; the latter is usually preferred since it guarantees easy installation and a homogeneous superficial temperature.

The principal heat transfer mode is connected to radiation, the coefficient of which is quite constant in each of the three arrangements above. What is different between a floor, ceiling or wall installation is the convention's efficiency. Warm air naturally moves toward the ceiling, while the cold one toward the floor. The phenomenon is due to the temperatures' difference that leads to a density's gradient; warm air is less dense and therefore it is lighter than cold air. This aspect explains better operation of under-floor panels for heating purpose and ceiling panels for cooling one. In particular, it has been demonstrated that:

- Ceiling panels have capacities up to 100W/m^2 for sensible cooling and 40-50W/m^2 for heating;
- Underfloor panels' capacities are up to 100W/m^2 for heating and 40W/m^2 for sensible cooling;

Indeed, while the radiant coefficient remains constant to about 5.5 W/m^2K in each configurations, the convective one decreases considerably if underfloor panels are used for cooling or ceiling panels are used for heating. Specifically, according to *A 50 year review of basic and applied research in radiant heating and cooling systems for the built environment*, the heat transfer coefficient of a UFH system is around 10 W/m^2K and more than half of the total heat transfer is due to radiation (5.5 W/m^2K). In case of cooling operation, the total heat transfer coefficient is 7 W/m^2K, the radiant part of which is always around 5.5 W/m^2K. Therefore, it is easy to highlight that the convective performance of an underfloor panel is nearly 50% lesser for cooling than for heating. On the contrary, both heating and cooling capacities account for 50 W/m^2 for installations on parietal walls, that is to say radiant and convective efficiencies do not change according to operation mode.

Although ceiling panels are more suitable for the cooling purpose, in the residential sector it is most common to identify underfloor systems that are used both in winter and in summer. The majority of households prefer to install hydronic systems that fulfil both heating and cooling demand. This is possible by installing a reversible heat pump or a pair of boiler and chiller, which provides warm water in winter or cold water in summer.

- Warm water in winter: from 30°C to 40°C
- Cold water in summer: around 16-18°C

The water temperature is regulated by a control system in order to optimize indoor thermal comfort and to minimize energy consumptions. Hence, the regulation of the plant allows meeting the effective load required by the habitation. There are three different regulation's arrangement adoptable:

1) *Fix point regulation*
   Is a kind of ON-OFF operation, room by room, according to which one can decide if turning ON or OFF the system. In this case, the water temperature is always constant besides thermal load changes. This regulation method is usually used for discontinuous applications.

2) *External climatic*
   Thanks to an external temperature sensor, the system regulates the water mix between outlet flow and return one. The water flow that arrives to radiant panels is constant but its temperature is regulated according to the outdoor one.

3) *External climatic with room compensation*
   The control system is equipped with two temperature sensors; by measuring both external and internal temperatures, it is able to evaluate how much the inertia of the plant is sufficient in order to respond to thermal load changes. For instance, it is supposed that the external temperature decreases for a while because of a cloud covering the sun; it is evident that the internal temperatures remain unvaried thanks to the house and plant's inertia, and therefore no regulation is expected. Hence, the control system with both external and internal temperature sensors is more accurate and it allows a better

management of the plant. In advanced applications, the regulation is realized both in the water mixer and in the heat pump (inverter).

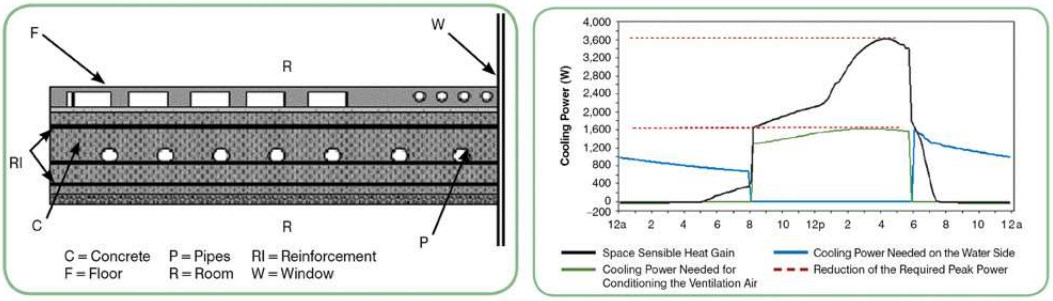
Together with the adjustment of the cooling load, the control system has another fundamental task that deals with condensation problem. The most critical aspect about radiant panels operation concerns with the possibility that some condensation may appear on the radiant surfaces. This phenomenon is more probable in hot and humid climate, where the "dew-point temperature typically exceeds the surface temperature of chilled ceiling or floor". Because of this, many manufactures and university research teams have conducted several studies in order to implement solutions in terms of configuration and control able to prevent condensation. Speaking of this, a control system adopted with temperature and humidity sensors can operate in two ways:

- The control system manages the radiant plant and controls dehumidification and ventilation elements.
- The control system checks that the radiant surface temperature is at least one degree higher than the dew point temperature. If not, the control system turns OFF the radiant plant.

It is clear that the more advanced is the control system, the greater is the expenditure related. Specifically, the price of a regulation system for managing a heating and cooling radiant plant, with control of dew point temperature, indoor air temperature and humidity, control of dehumidification and ventilation side, can account for about 2000€ (+20€/m^2).

The radiant technology is characterized by a certain inertia since it uses the structure in which it is installed in order to give or absorb heat. This is the reason why such plant has a longer response time compared to other solutions as FCUs and splits. While with the latter the control of internal temperature is almost immediate, with radiant panels the same takes some minute and the time needed becomes bigger (a couple of hours) if we consider starting or stopping times. Therefore, the thermal inertia involves considerable differences between starting/stopping times and those of effective use. Radiant panels are suitable for application with constant cooling load during summer; on the contrary, residential cooling is an individual and fluctuating matter, variable and the system has to be able to respond promptly to the cooling demand. Indeed, manufactures have developed low-inertia solutions, which are characterized by lower insulation thickness and hence response time. However, they have

larger heat dispersions toward the undesired direction. For instance, ceiling panels are described by a lower thermal mass compared to other radian solutions and they are more suitable for fast adjustment due to indoor load changes.



Example of position of pipes in thermo active building systems (TABS).

Theoretical example of peak-shaving (reducing the peak load) effect (time versus cooling power [W]).

Figure 29 – TABs (Source: ASHRAE Journal, vol. 54, no. 3, March 2012)

A part from common radiant systems and low-inertia ones, there is also a high-inertia configuration, TABs. TABs, or thermal active buildings systems, consists in heating and cooling surfaces made by pipes, which are embedded in the central concrete core of the building construction. They are usually used for multistore buildings' cooling and, since they are described by larger thermal mass, they are suitable mostly for application with a constant demand during daytime. In the majority of cases, TABs are coupled with a ventilation system; during daytime the cooling effect is fulfilled by the latter, when the supply air temperature is lower that the exhaust one. During the night, the ventilation rate is reduced and the circulation of cool water removes the heat stored in the concrete slabs. According to this configuration, dimensions of the airside are more compact since only ventilation is needed and suspended ceilings are avoided. However, in general, TABs guarantee a reduction of the cooling peak during daytime, that is to say they decrease the peak power consumed in order to fulfil the maximum load. It is possible by cooling the structure during a period in which occupants are absent and cooling is not effectively required, and then by exploiting the high thermal inertia of the system. This way, energy costs[21] can be lower, as well as the generator's investment is cheaper since the reduction of the cooling peak involves a reduction in the size of chiller/heat pump too.

One of the fundamental characteristic of the radiant technology is the emitters' dimensions. While in case of FCUs and splits the emitter is compact, visible and localized in

[21] The energy costs can be reduced using the lower night time electricity rate

a precise position, radiant panels cover the whole room's area. This feature makes radiant panels to be one of the best air conditioning technologies but at the same time one of the most difficult and expensive to install. The installation of the same is quite complicated, especially in case of refurbishment or renovation, and therefore investment costs are high[22]. Nevertheless, the emitters' surface amplitude is the source of many benefits, as:

- **Less energy consumption**
  The larger exchange area allows reducing the temperature difference between indoor air and operative fluid. A lower difference between temperatures mentioned makes it convenient to use generators, the efficiency of which increases by decreasing the water temperature needed. This is the reason why radiant panels well matches with heat pumps, solar panels, condensing boilers and heat recovery unis. Furthermore, a supply temperature closer to the indoor one reduces heat losses in pipes, as well as convective motions on windows, which are the main causes of dissipations. In summary, a radiant system involves an average energy saving of about 10-15% compared to traditional plants.

- **Improving of comfort level**
  Since the emitter covers the whole room, the effect supplied spreads homogeneously, without convectional flows that can be source of discomfort. In other words, the air speed is reduced so that no undesired airflows are perceived. This is ensured by the fact that radiant panels increase the portion of radiant heat exchange between surfaces and people.

- **Invisible emitters**
  Besides larger exchange surfaces, radiant panels are invisible and therefore they allow a global use of parietal walls, ceiling and floor. Indeed, radiant systems do not impose aesthetic conditions as FCUs and splits do, and they do not limit the freedom of furniture.

An important element of assessment relates to the comfort quality ensured by radiant technology. In particular, it is commonplace to compare radiant panels as an expensive

[22] CALEFFI affirms that radiant systems are more expensive of 10-30% than radiators with climatic regulation

solution, with a critical problem connected to humidity condensation during summer, but at the same time as an air conditioning alternative that guarantee better energy performances during its operation and superior comfort levels. In reality, some considerations have to be made according to comfort level, since some advantages and disadvantages are identifiable. Here there is a list of pros and cons:

- Radiators and fan coils, as high-temperature heating systems, realize the combustion of dust, resulting in irritation of nose, eyes and throat of occupants. On the contrary, radiant panels, as low-temperature heating emitters, avoid the combustion of the same. Furthermore, thanks to the greater radiant contribution and the lower convective one, compared to traditional air-conditioning systems, radiant panels prevent a high circulation and excessive movement of dust, cause of allergies and breathing difficulties. In the end, underfloor radiant panels avoid the formation of wetlands, nice setting for mites and bacteria, and the origin of mildew on the walls. Furthermore, they do not contribute to parietal walls' degradation because of black smoke as radiators and fun coils do.

- Radiant panels guarantee a better comfort perception through better temperature distribution and a lower presence of convection flows.

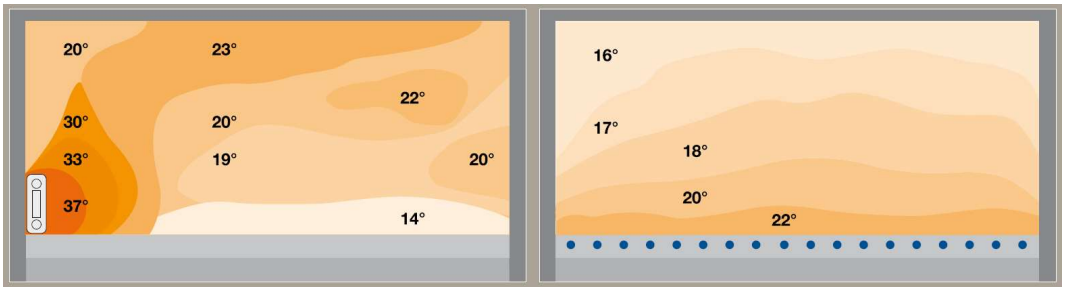


Figure 30 - Temperature Distribution with Radiant Panels (Source: RDZ Brochure)

- Radiant technology has a limited capacity for cooling because of the impossibility to reduce excessively the water temperature. This is due to the strong attention to avoid condensation. Nevertheless, in the current European scenario, there are not significant residential application for which radiant panels are not sufficient in order to fulfil sensible cooling.

- The principal disadvantage of radiant panels is connected to the fact that such emitters do not achieve any latent load treatment. This is the reason why such devices are not suitable for hot and humid climates, where a precise control on humidity is required in order to avoid undesired condensation on radiant surfaces. Nevertheless, radiant panels can be coupled with a dehumidifier. This way, radiant panels manage the sensible cooling load while the dehumidifier realizes the humidity control with new or recirculated air. The main advantage is the insertion of dehumidified air at the same temperature of the indoor environment one; therefore, no cold current is created and discomfort because of chilled airflows is reduced.

Some considerations have to be taken into consideration regarding radiant technology in terms of costs and design. First, since many years radiant panels have found a strong difficulty to penetrate the market because the majority of European households has considered the same as an expensive solution and with a complex installation. Nonetheless, manufactures have improved their products toward cheapness and installation facility in order to fulfil families' requirements. Current technology's prices are:

- Underfloor panels: from 30-40 €/m^2 up to 80 €/m^2 (UFH&C: prices from 50 €/m^2)
- Ceiling panels: from 60-80 €/m^2 to 160 €/m^2

Another aspect that increases costs is the design phase. It is required a design phase of the system before installing the same and this, as well as making the plant less suitable to changes both in work progress and when it is completed, rises the investment for the costumer. However, one should remember that radiant panels allow energy and money saving in operation compared to a traditional system and therefore they let to depreciate in relative short term the higher price paid for their installation.

Hence, which are the main room of improvements for radiant panels? Technologically speaking, the development process seems to be quite stagnant since many renovations have been made so far. Specifically, the progress has based on different guidelines, as lower selling costs and a greater product's diversification in order to fulfil costumers' requirements. However, thanks to UPONOR internal experts' interviews, it has been possible to recognize that the main innovation driver has concerned the research of ways to simply and speed the installation procedure, not only in new buildings but especially in case of refurbishment and

renovation of existing ones. New developments seem to deal with prefabricated components, that is to say the realization of systems that require less effort during design and installation phases and therefore can simplify the procedure between producer and costumers. Another target concerns with radiant panels matched with dehumidifiers, in order to provide higher comfort level in terms of both sensible and latent load control, as well as to ensure in some cases air change and purification. Indeed, currently, achieving complete control of sensible and latent loads requires a system more complex and expensive than those splits' manufactures propose.

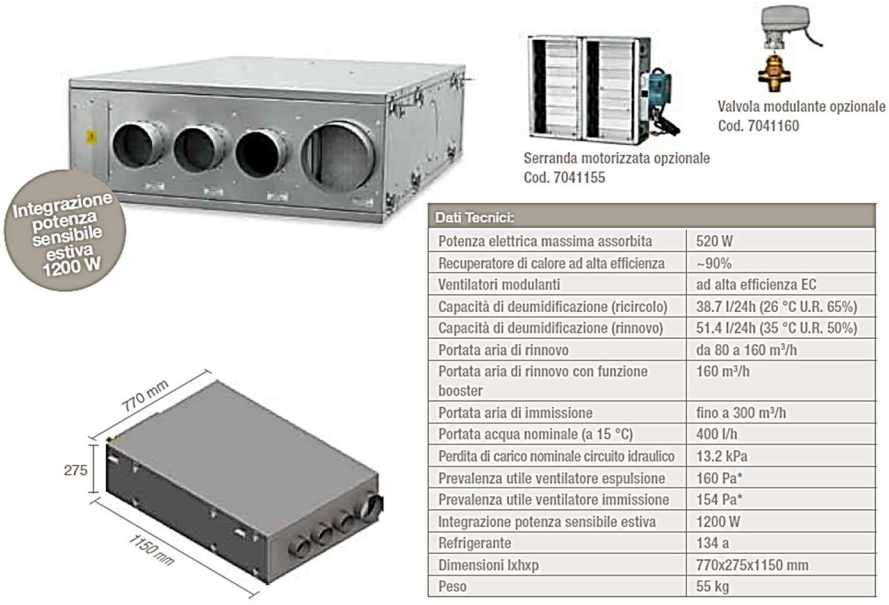
DEHUMIDIFIERS WITHOUT FRESH AIR VENTILATION – RNW (RDZ)

A dehumidifier RNW consists in a refrigerant machine with two heat exchangers that exploit the availability of chilled water (15-18°C) used in radiant panels. The first is a pre-treatment battery, which lowers the recirculating air temperature, removing sensible load. The post-treatment battery, on the contrary, is positioned after condensation and evaporation batteries, operating with refrigerant, and it reduces the temperature of air before being released back into the indoor environment. This system allows obtaining dehumidified air at the same indoor environment's temperature. The refrigerant is first evaporated in the phase of air's dehumidification and is then condensed in the heating phase of the latter. Therefore, a RNW dehumidifier controls only the latent load. A dehumidifier can be installed in the floor, wall or in the ceiling. In all configurations, the machine is quite compact and silent; hence, it can be applied to residential buildings. The price of a dehumidification system for a habitation of about 100 m^2 can be around 1500-2000€ (+ 20 €/m^2).

DEHUMIDIFIERS WITH FRESH AIR VENTILATION – Unit Comfort UC (RDZ)

The 'Unit Comfort UC' is a kind of air handling unit, which has the main scope to threat the air through high-efficiency recovery and dehumidify the same. The principal features of the machine are the ventilation with renewal and recirculating air, summer dehumidification, as well as in some cases the integration of sensible load, both in heating and cooling mode. A Unit Comfort UC device handles both renewal and recirculating air, dehumidifying and releasing the primary flow at the same indoor temperature. For instance, we can consider room air at 26°C and R.H. of 65% and outdoor air at 35°C and R.H. 50%; the product considered is able to provide primary air at 26°C and R.H. of 48.3%. Therefore, the main advantages are connected to dehumidification, ventilation and the release of no cold air.

The price of a dehumidification system with VMC[23], for a habitation of about 100 m^2, can be around 5000€ (from +40 €/m^2 up to +50 €/m^2). Furthermore, one has to consider the contribution of the channelling system for the dehumidifier and the ventilation element with heat recovery, which accounts for 3200€.



Dati Tecnici:	
Potenza elettrica massima assorbita	520 W
Recuperatore di calore ad alta efficienza	~90%
Ventilatori modulanti	ad alta efficienza EC
Capacità di deumidificazione (ricircolo)	38.7 l/24h (26 °C U.R. 65%)
Capacità di deumidificazione (rinnovo)	51.4 l/24h (35 °C U.R. 50%)
Portata aria di rinnovo	da 80 a 160 m^3/h
Portata aria di rinnovo con funzione booster	160 m^3/h
Portata aria di immissione	fino a 300 m^3/h
Portata acqua nominale (a 15 °C)	400 l/h
Perdita di carico nominale circuito idraulico	13.2 kPa
Prevalenza utile ventilatore espulsione	160 Pa*
Prevalenza utile ventilatore immissione	154 Pa*
Integrazione potenza sensibile estiva	1200 W
Refrigerante	134 a
Dimensioni lxhxp	770x275x1150 mm
Peso	55 kg

Figure 31 - Dehumidifier with Fresh Air Ventilation (Source: RDZ Brochure)

UPONOR FLOOR INSTALLATIONS

- *MINITEC*

  Uponor Minitec is characterized by a low thermal inertia since the system takes up only 15mm, allowing installing the same in renovation works, even directly over the existing floor or parietal walls.

- *KLETT*

  Uponor Klett offers an innovative and fast method of installation for underfloor radiant panels, without the use of accessories such as clips, clamps and rails. Uponor Klett pipes are already supplied with a spiral strip for quick and easy coupling. The strip adheres well to the layer of fixing and pipes are kept in the desired position, ensuring a maximum seal. The installation of Uponor Klett is up to 50% faster than other systems adopted with clips or rails.

[23] VMC = mechanical ventilation control

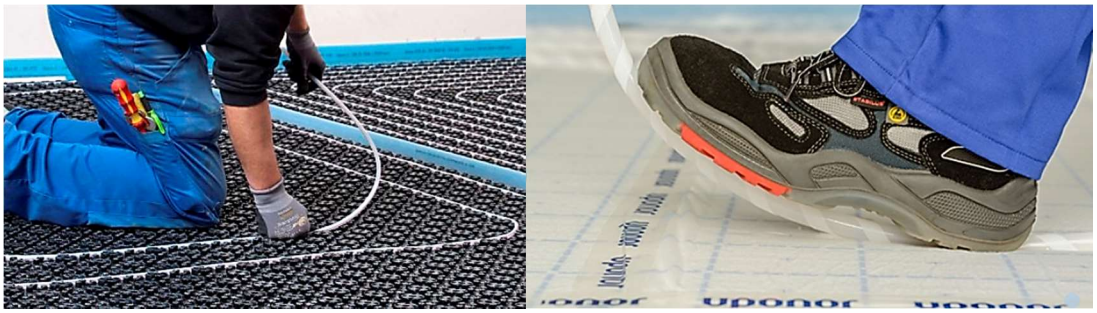


Figure 32 - Minitec and Klett (Source: Uponor)

- *SICCUS*

  Uponor Siccus is another low thermal inertia solution made by Uponor, which is an optimal alternative for refurbishment of residential buildings; moreover, it is suitable for new constructions. The installation is simple and fast, and the system can be installed directly over the existing floor since the overall height is 43mm. In the end, Uponor Siccus has low static weight.

- *TACKER*

  Uponor Tacker provides great installation facility and flexibility, since pipes can be fixed through clips, being adaptable to all types of indoor environment and guarantying proper comfort. The overall height is 74mm.

Figure 33 - Siccus and Tacker (Source: Uponor)

<u>UPONOR WALL AND CEILING INSTALLATIONS</u>

- *RENOVIS*

  Uponor Renovis consists in a panel of 15mm in which PEX pipes 9.9mm are included; integrated pipes within the panel simplify the installation to the wall or ceiling and guarantee optimal performances both for heating and cooling. It is suitable for new construction as well as for applications in existing buildings.

- *TEPORIS*

  Uponor Teporis is integrated in the suspended ceiling structure and it is easy to match with other systems for ventilation, lighting of fire prevention. Uponor Teporis is provided with PEX pipes in a panel of 15mm and with an insulating layer in EPS, which improves the thermal efficiency, facilitating the heat exchange with the environment and preventing dispersions toward the undesired direction.

Figure 34 - Renovis and Teporis (Source: Uponor)

5.3 Room Air Conditioners

5.3.1 SPLIT AIR CONDITIONER

The split air conditioner is a cooling device that has had a dominant success, from China and Japan, until Europe, where it was introduced with the main summer cooling purpose in commercial and residential buildings. Split system operates on direct expansion principle, through which heat is transferred from conditioned space toward the external environment by circulating a refrigerant fluid. R410A and R407C are the substances that are currently used in these products, the former principally for low capacities, while the latter for high sizes. The operating cycle is simple and it consists in two main sections; all components above are carefully designed in order to perform optimum efficiencies in a range of climatic conditions. The outdoor unit can be installed on a flat roof, on a balcony or wall mounted using suitable brackets; the indoor unit should have different locations according to internal emitter typology

- OUTDOOR UNIT: Compressor, heat exchanger and fan
- INDOOR UNIT: Heat exchanger and fan
    - Cassette (commercial application)
    - Ceiling suspended
    - Wall mounted
    - Floor standing

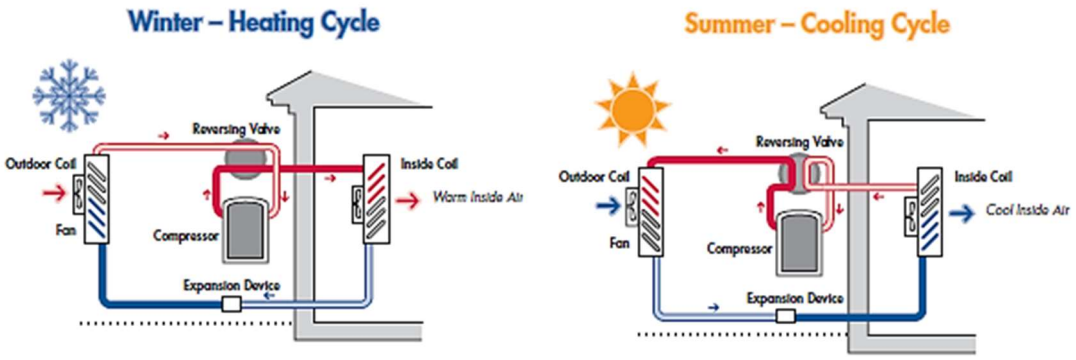


Figure 35 - Air Conditioner (Source: High Efficiency Air to Air Heat Pumps)

There are three main configurations of split air conditioner systems and therefore they are described by different peculiarities and operating characteristics. In particular, the movement from the simpler arrangement toward the more complex one has represented the

evolution of the technology itself, which started from single-splits and it has now reached the state of art position with the modern VRV/VRF[24]. These configurations differ on the design and operation of the refrigerant circuit; however, the principle of direct expansion remains as common denominator in all three systems. Common advantages and disadvantages of split technology are described in the *Single-Split* section, while differences are underlined in each paragraphs.

Figure 36 - Internal Units Split Conditioners (Source: Daikin)

5.3.1.1 SINGLE-SPLIT

Single-split air conditioner system is one-to-one configuration made by one indoor unit and one outdoor unit. Although more than one single-split is needed to cool different rooms, with many outdoor units as there are indoor, several households have installed just one element in order to fulfil the thermal demand of different habitation's areas. This is possible by keeping rooms' doors open and making cooled and ventilated air flowing through the same. On the contrary, if the dwellings is widespread, more emitters are necessary.

In addition, it is fundamental to take into consideration that cooling demand is mainly concentrated in the evening, when people come back from work. This aspect has had a deep influence on the system's typology preferred by European families; in particular, many customers prefer to install a cooling device just for some rooms or house's areas. This has led single-splits to cover a dominant role in the residential cooling market.

As previously mentioned, there are different aspects to highlight concerning split technology; some of these are positive and make split products to be the most dominant solution in the European cooling scenario, for both residential and commercial application. Nevertheless, there are also some negative features, which are source both of comparison with other cooling applications and of development for splits' manufactures. Therefore, a list of pros and cons has been proposed, with some comments and considerations on the same.

[24] "The VRF technology/system was developed by Daikin Industries, Japan who named and protected the term 'variable refrigerant volume' (VRV) system so other manufactures use the term VRF 'variable refrigerant flow'. In essence both are same" – *HVAC Variable Refrigerant Flow Systems*

- Split technology has the great merit to guarantee perfect air temperature and humidity regulation, together with the purification of the recirculated air. While split solution ensures a complete and high quality air treatment in just one element, hydronic systems need an air section in order to fulfil latent demand. For instance, both fan coils and radiant panels have to be coupled with dehumidifiers or AHUs for assuring humidity control.

  - Split system does not achieve ventilation/air change.

  - The air conditioner picks up some air, which is released in a short time in the indoor environment after being dehumidified and cooled. The fan favours convective motions between handled air and the room's one. In other words, split creates cold air jets, which can cause discomfort and neck pains. Moreover, although forced convection tries to favour perfect air mixing, a non-uniform temperature distribution can be measured inside the room. It is possible to perceive cold spots along the trajectory of the cold air jet.

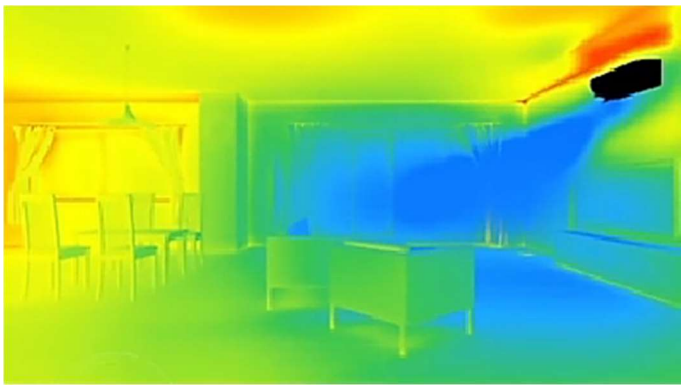


Figure 37 - Temperature Distribution with Single Split (Source: Daikin)

- Manufactures has a wide range of products, which allows customers to choose the style and performances that fit more with house's demand. Furthermore, households can compared solutions that are more or less expensive; in general, the application of a split system is economically affordable and it takes investment from 1000€ up to 3000€. It is evident that initial costs of a single-split are lower compared to other cooling applications.

- The installation procedure for a split application is simple, quick and flexible. In particular, one should speak about split's adaptableness according to different aspects:

    - Sector's adaptability: splits are suitable for both commercial and residential edifices.
    - Building's adaptability: splits can be integrated in the construction project of a building or they can be installed in existing edifices with great facility. Installation facility is due to low spaces occupied by indoor and outdoor units, as well as by refrigerant ducts. In other words, split system's components are compact, easy and quick to apply to new or prebuilt constructions.
    - Residential adaptability: splits product are suitable for each habitation's typology, single or multi-unit one. In particular, flats are described by less extension and strong proximity to other houses; split technology fulfils the prerequisites for an unobtrusive solution, suitable for little spaces and that does not create inconveniences to other apartments.
    - Climate adaptability: split system is suitable for each summer climatic condition, especially for hot and humid ones.

    - The aesthetic impact of the outdoor units is huge and therefore installers favour hidden locations or at least barely visible to most. This is the reason why, in case of more than one internal emitter, multi-splits represent a better aesthetic solution because different indoor units can be connected to just one outdoor unit. The effect of many outdoor condensers is even emphasized in the case of apartment block, where it is unpleasant to observe facades covered by external elements. This occurs even for hydronic application, for which, however, it is more common to install a centralized system instead of an individual one for each habitations. In this scenario, VRFs could be an excellent centralized alternative for multi-family applications.
      In addition, indoor units are not completely invisible and sometimes they can have an undesired effect on the internal look of the house. Nowadays,

producers are developing solutions with modern and elegant designs, which have better integration with the furniture.

- Outdoor and indoor unit are noisy because of fans; acoustic problematics are emphasised in the case of external section, in which the compressor is included. Therefore, it is fundamental to choose external locations in order to avoid the same to disturb because of its noise.

- There is a limitation on the distance between the indoor and outdoor unit, which accounts for about 30-45 meters.

- A significant property of split technology concerns the system and emitter's control. It is possible to manage every internal unit independently, in order to obtain the desired temperature just in the rooms where it is needed. Moreover, the respond time is short; for instance, after the starting time, the system takes just few tens of minutes to provide comfortable conditions in the rooms.

- The operation of the external component, and therefore of the entire plant, is limited in case of extremely high or rigid temperatures. Nevertheless, no specific examples of problems have been recorded in summer up to now; on the contrary, the operation in heat pump mode is quite complicated in rigid Nordic climates.

The split technology has experienced large progress up to now, mainly in response to negative aspects previously highlighted. For instance, developers have improved the products toward solutions that ensure a more careful circulation of the airflow, in order to avoid occupants' discomfort and inhomogeneous air temperature distribution. Specifically, three innovations have been introduced in the current offers:

1. Control of the air jet's direction: thanks to presence sensor, it avoids releasing the air jet on occupants.
2. Three-dimensional air jet: thanks to horizontal and vertical oscillations, it is possible to release the air jet in a more homogeneous way in the room.
3. Different air circulation for heating or cooling: since it is known that warm air rises and cold falls, the air jet can have different inclination of releasing according to the thermal purpose.

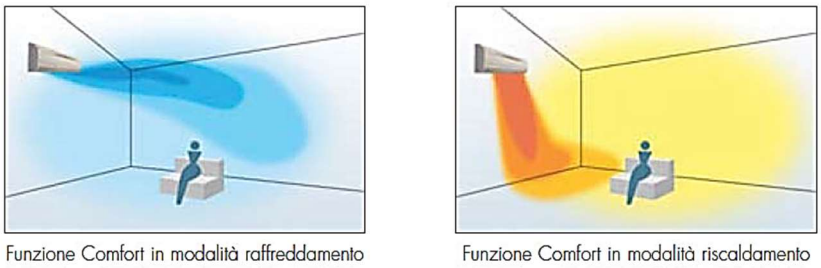


Figure 38 - Airflow Direction (Source: Daikin)

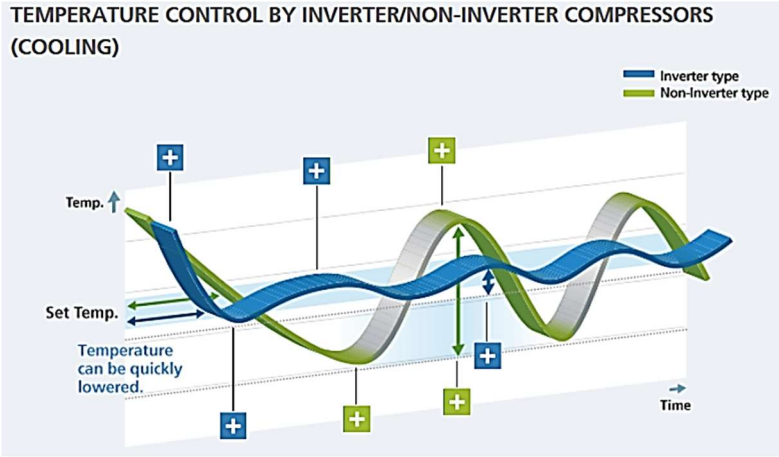


Figure 39 - Temperature Control by Inverter (Source: Daikin)

Technologically speaking, other two fundamental innovations deal with reversible alternatives and the introduction of inverter solution. As concern the first one, currently, manufactures propose the majority of product in heat pump configuration, suitable for both heating and cooling. Inverter technology is applied to all compressors (in some cases it can be used also for fans in order to provide a more precise control and energy saving). The inverter modulates power supply frequency to control motor rotation speed; it stabilizes temperature by adjusting compressor operation according to the thermal load effectively required, in order to eliminate wastes and to save energy. Indeed, according to Daikin, thanks to inverter, split technology can have a reduction of 30% of energy costs, a part from a better indoor comfort level ensured.

DAIKIN EMURA

Daikin Emura allows customers to create a refined and elegant climate control and to guarantee high air quality:

- A filter absorbs particles, decomposes odours and inactivates the production of viruses, bacteria and microbes.
- It combines vertical and horizontal oscillations to allow a homogeneous distribution of air throughout the room.
- It ensures operation without undesired airflows, avoiding that the same are directed towards occupants.
- It is possible to have a complete control of emitters thanks to Apple or Android systems.

Figure 40 - Daikin Emura (Source: Daikin)

DAIKIN URURU SARARA

Figure 41 - Daikin Ururu Sarara (Source: Daikin)

Daikin Ururu Sarara can be considered the state of art for split air conditioners. Ururu Sarara solution can fully control the air quality, in terms of temperature regulation, humidification and dehumidification, renovation and purification of the air. Furthermore, it seems to be the most efficient one on the market, for both heating and cooling, and the first to use the new refrigerant R32.

- *Humidification*: the humidification system is limited to absorb the right amount of moisture from the external environment in order to humidify the

indoor air, which, if too dry, will seem colder and cause problems to throat and skin.

Dehumidification: the dehumidification system moved automatically and efficiently excess moisture to the outside, maintaining indoor temperature constant.

- *Ventilation and purification*: unlike traditional air conditioners, Ururu Sarara brings fresh air (32m^3/h) into the room and purifies the same by passing through filters for dust and pollen. Filters also removes odours, such as cigarette and kitchen smoke.

- *Intelligent eye*: Daikin has developed a motion sensor that both decreases or turns off the power if occupants are absent and directs the airflow away from people that are in the room.

- *Self-cleaning technology*: it is necessary to clean filters once a year, because the greater is the number of particles on the same, the lower is their efficiency. The self-cleaning technology has made obsolete other air conditioners.

- *High efficiency*: Ururu Sarara is available in capacities from 2 to 5 kW. They are in class A+++ and their SEER and SCOP[25] can reach respectively values of 9.54 and 5.9, which make the same the most efficient air conditioner on the market.

- *R32*: one of the main guideline for further development deals with refrigerant fluids, since the F-gas regulation has established stricter limits in terms of acceptable GWP values. The R32 has a GWP of 650, which is 67% lower than the R410A GWP of 1975.

5.3.1.2 MULTI-SPLIT

Multi-split systems consists in multiple indoor units connected to one external condensing element; at least nine/ten internal evaporators can be installed and they operate in

[25] SEER = seasonal energy efficiency ratio for summer and SCOP = seasonal coefficient of performance for winter

the same mode all together, that is to say all cooling/OFF or heating/OFF. It is immediately evident that the possibility to install just one condensation component for multiple indoor units permits to reduce external space occupied, as well as to limit aesthetic impact on the façade. Furthermore, it is possible to apply emitters of different typology and capacity and the same do not have to be installed simultaneously; an extension of the system can be projected. The peculiarity of such configuration concerns the fact that each indoor unit has its own refrigerant circulation pipes. Therefore, this solution allows having an individual control on emitters that can operate or not. Nevertheless, multi-splits are suitable for rooms with similar thermal characteristics, that is to say it is not possible to have simultaneously cooling and heating.

Since multi-splits operate on the same principles as a single-split system and use same emitters, they are characterized by same advantages and disadvantages. However, investment costs are different and for multi-type air conditioners they are divided according to outdoor and indoor unit.

- Outdoor unit: around 2000€ or even lower for a condensing element of 5kW, up to 5000€ for an outdoor unit of 20kW.
- Indoor unit: for wall mounted devices, that is to say the most common ones in residential applications, the price is from 400€ up to 1400€ for advanced solutions as Daikin Emura. Therefore, compared to a multi single-split's installation, multi-splits are more convenient when indoor units are over 4-5.

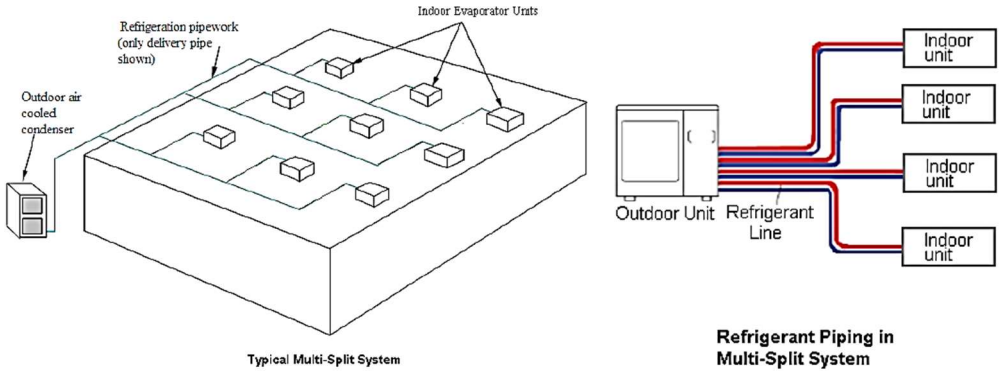


Figure 42 - Multi-Split System (Source: HVAC Variable Refrigerant Flow Systems)

5.3.1.3 VARIABLE REFRIGERANT FLOW – VRF

VRF systems are very similar to multi-splits since in both configurations multiple indoor units are connected to a single outdoor unit. Nevertheless, a substantial difference in operation distinguishes VRV systems from the multi-split ones. In particular, the VRF

configuration represent the last progress stage of split technology. VRF systems work by continuously controlling and varying refrigerant flow rate that operates each internal emitters. This special control is possible thanks to the combination between pulse modulating valves (PMVs) and indoor thermistor sensors. The latter identify the cooling demand of the room and send this information to a microprocessor that regulates PMVs. By doing so, the refrigerant flow is regulated in order to satisfy, with precision and continuity, the thermal load effectively needed. The change of the total domestic demand varies the one produced by the external element, which matches the global cooling/heating load by adjusting scroll-compressor speed. Specifically, the capacity control range can be as 6% to 100%. Therefore, the system have a perfect connection between the stabilization of the load thanks to inverter technology and the matching of the demand effectively required by rooms by varying the refrigerant flow that operates each internal emitters. In addition to this, Daikin has developed a new solution (*VRV IV*) that achieves refrigerant temperature's regulation together with refrigerant flow's one, the combination of which has led to a 28% increase of seasonal performances.

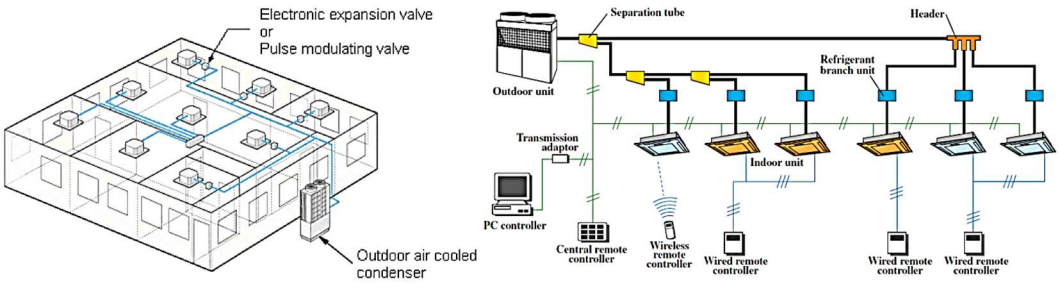


Figure 43 - VRF System (Source: HVAC Variable Refrigerant Flow Systems)

Another feature that makes VRF different to multi-split and that allows refrigerant volume variation concerns the circuit configuration; a single refrigerant piping plant characterizes VRF systems while in multi-splits each indoor unit has its own set of refrigerant pipe work. Hence, VRVs minimize the use of pipes and so reduce annexed costs compared to multi-type air conditioners. Furthermore, this allows maximizing the efficiency of refrigerant work too. It is also important to consider that VRF configuration permits the installation of about 48 indoor units of different typologies and capacities, decidedly higher that those possible in multi-split arrangement. Nevertheless, there are some restriction concerning refrigerant plant lengths:

- Maximum allowable vertical distance between outdoor unit and its farthest indoor unit = 50m

- Maximum allowable vertical distance between two individual indoor unit = 15m
- Maximum refrigerant piping lengths between outdoor unit and its farthest indoor unit = 165m

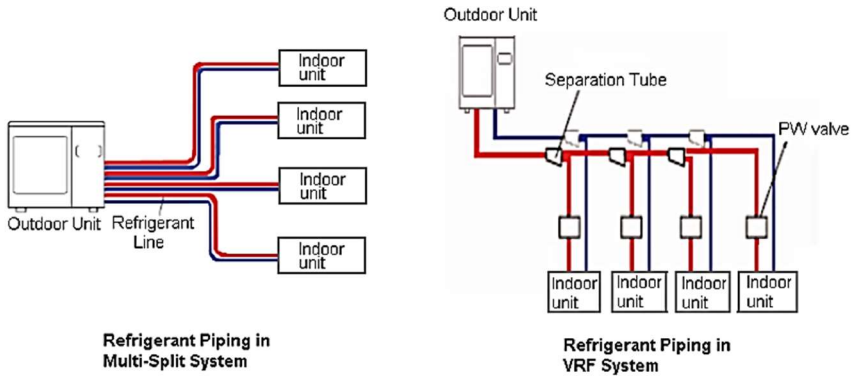


Figure 44 - Comparison between Multi-type and VRF (Source: HVAC Variable Refrigerant Flow Systems)

Two configurations of VRF system exist, that is to say *VRF heat pump* and *VRF with heat recovery*.

1) *VRF heat pump system*:
   All internal emitters can operate simultaneously in only cooling mode or in only heating one.
2) *VRF with heat recovery:*
   VRF with heat recovery system allows internal emitters to work simultaneously in heating and cooling mode providing at the same time different effects in different areas of the building. Specifically, each indoor unit is connected through 3 pipes: one liquid line, one hot gas line and one suction line. A solenoid valves control the operation of the three-pipe system. The system usually includes extra heat exchangers between refrigerant used for cooling and the one for heating; indeed, it is possible to recover some heat from the superheated refrigerant exiting from areas that have been cooled and to release the same to the refrigerant that is going to heat other zones.

   - In cooling mode, liquid and suction line are operating; the refrigerant exits from the liquid line and enters in the suction line. The emitter works as an evaporator.

- In heating mode, gas and liquid line are open; the refrigerant exists from the gas line and enter in the liquid line. The emitter operates as a condenser.

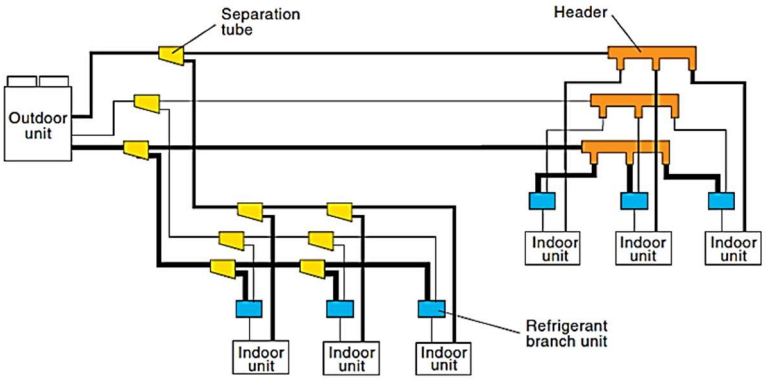


Figure 45 - VRF Scheme (Source: HVAC Variable Refrigerant Flow Systems)

- The VRF system can be expand in a phase following the installation one.

- Some consideration about investment costs are fundamental. In particular, it seems that VRF systems' cost is estimated to be 5% to 20% higher than air or water-cooled chilled water system. At the same time, according to *HVAC Variable Refrigerant Flow Systems*, considering 10 indoor units, "a VRF system reduces installation costs by about 30%" compared to multiple single-split plants. In order to be more detail, current VRF prices are:

  - Outdoor unit: from 5000€ to 6000€ for capacities closed to 20kW, with possibility to install at least 8 indoor units.
  - Indoor unit: prices of indoor units are similar to ones mentioned for multi-type air conditioners.

One of the most challenging aspects of designing VRF systems is the introduction of outside air in order to guarantee an acceptable ventilation level and air quality. Therefore, it is necessary to provide an auxiliary ventilation system, in the majority of cases including a heat recovery element between outside air and exhaust air. Another room of improvement concerns with the fact that manufactures are improving VRF systems toward plug-and-play solutions, that is to say compact and standardized products, in order to minimize design phase and facilitate installation procedures. Furthermore, producers have the goal to offer low-capacities alternatives, for small commercial applications and for the residential segment. Nowadays,

VRFs can be suitable for installations in multi-family houses, as centralized systems mainly for cooling purpose. However, it is possible that such technology would gain some considerations also for space heating. Apartment blocks are characterized by different thermal demands according to households' requirements. VRFs satisfy prerequisites of flexibility in case of different and variable thermal loads, and, in particular, they can also ensure simultaneous cooling and heating. This is a fundamental feature even if in the residential sector it is improbable to have a contemporaneous request of heating and cooling.

5.3.1.4 DUCTED SPLIT AIR CONDITIONER

A ducted split air conditioner operates according to the same physical principles of split technology. Therefore, the main difference consists in the presence of air ducts, which collect exhaust air and lead the same to a ceiling indoor unit where it is handled. After the treatment, the air is released again to rooms. By doing so, all the rooms are conditioned in the same way. Nevertheless, the necessity of air ducts makes the system more invasive for the house structure, more expensive in terms of investment costs, as well as more complex for the installation, especially for refurbishment's applications.

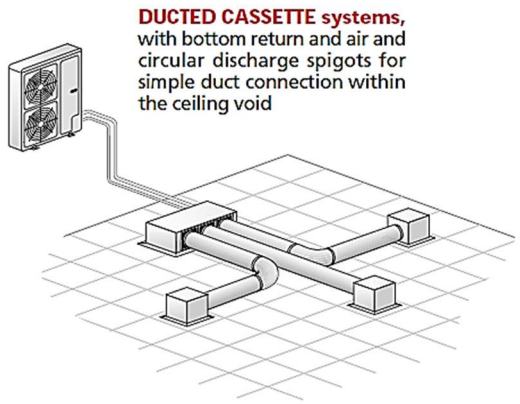


Figure 46 - Ducted Split (Source: R407C, the Engineers Guide)

5.3.2 PORTABLE/MOVEABLE AIR CONDITIONER

A portable air conditioner is a domestic device, generically used for home cooling, which has the feature to be moveable. A portable system has an indoor unit on wheels; nonetheless, it is quite difficult to move the same because of its weight, especially on carpets or over raised thresholds between rooms. It works in the same way a typical household split air conditioner does; it consists in a refrigerant circuit through which the fluid evaporates by

cooling the 'primary air' and condenses thanks to exhaust air. The hot air coming from the condenser has to be released outside and this is the reason why moveable air conditioners have to be located just close to windows. In particular, the machine is provided of an air duct, which expels the warm air used for the condensation of the refrigerant fluid. Therefore, the air conditioner can be moved before and not during operation. In order to be more precise, there are two configurations speaking about the hose system:

1. *Monoblock*: the water collected by dehumidifying the primary air is stored in a bowl and the air conditioner stops when it is full.
2. *Air-to-air*: the water collected by dehumidifying the primary air is evaporated in the exhaust air in order to guarantee continuous operation of the machine.

One problematic concerning the indoor unit is the presence of all its elements inside the room. Specifically, portable air conditioners are quite noisy since the movement of air, both for the evaporation and condensation, together with compressor operation can make an undesirable noise.

Moveable air conditioners are either evaporative or refrigerative. As concerns the latter, the air is cooled and dehumidified; on the contrary, according to the former arrangement, the liquid water is evaporated into the primary air and cools down the same by absorbing a significant amount of heat. "Evaporative coolers have the advantage of needing no hoses to vent heat outside the cooled area, making them truly portable"[26]. Furthermore, such systems are cheaper compared to refrigerative ones, whose average cost is from 300 to 500€. They use also less energy. Nevertheless, the evaporative technology can be suitable only in dry climates; in humid areas, the main goal deals with precisely the dehumidification of the indoor air, since the humidity of the same change the perception of heat and the one of the internal temperature.

Figure 47 - Portable Air Conditioner (Source: De'Longhi)

[26] Wikipedia, Air Conditioning – Portable Evaporative System

5.3.3 WINDOW/THROUGH-THE-WALL AIR CONDITIONER

Window and through-the-wall air conditioners are also called single-packaged units, even if the first two names are more commonly used. As well as moveable devices, single-packaged elements operate according to split technology; they consists in a refrigerant circuit, one side in contact with the outside air and one side interacts with the indoor environmental. The interior air is cooled as a fan blows it over the evaporator; the heat drawn from the interior is dissipated into the environment as a second fan blows outside air over the condenser. An insulating wall generically divides the two sides mentioned, which can be installed usually under a window or above a door. There is another configuration available designed to be applied in a window opening. Although single-packaged air conditioners are economically convenient, with average prices between 100€ and 400€, and easy to install, such devices are quite obsolete and, as well as portable products, they are going to be replaced by more cutting-edge technologies. Furthermore, one may also consider the aesthetic impact on the outside façade and the indoor ambient, if imaging that each rooms have to be cooled by air conditioning elements into consideration.

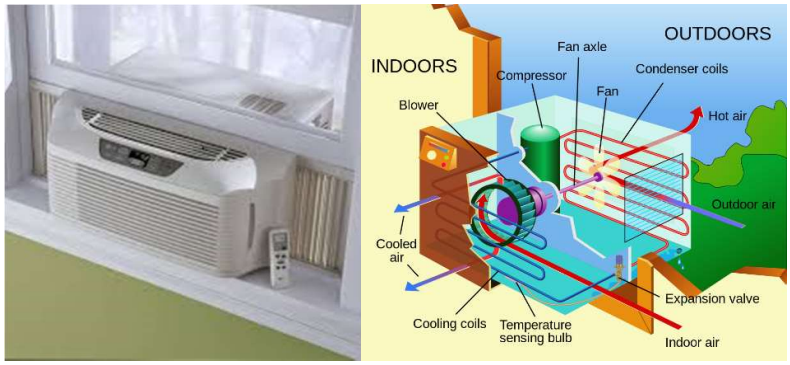


Figure 48 - Window Air Conditioner (Source: Wikipedia – Air Conditioners)

5.4 All Air Systems

5.4.1 PACKAGED AIR CONDITIONING SYSTEM

An air-handling unit regulates and circulates air, as part of a heating, ventilation and air conditioning system (HVAC). When speaking about AHUs, the majority of experts refer to 'all air conditioning systems', which are plants that use the air as operative fluid in order to bring sensible and latent heat loads. In other cases, this equipment is also defined as 'centralized air cooling system' since the air treatment is carried inside a single element. In reality, none of these definitions is wrong; with the term 'air handling unit' one should refer to several products, as well as different configurations of the same. Therefore, all air systems and packaged ones represent the same arrangement of an air conditioning plant characterized by a centralized treatment for the air and the use of the latter as carrier fluid for thermal loads. In particular, inside the component into consideration, the air is handled in order to achieve temperature and humidity's levels required, as well as the purification of the same. This is possible thanks to different components:

- *Filters*: the air filtration is in the majority of cases present in order to provide clean air to building occupants. Filters are usually placed as first element in an AHU; doing so, it is possible to keep all the downstream components clean and to avoid damages to the same.

- *Heat exchanger coils*: heat exchangers are used in order to heat or cool the air before releasing the same into the indoor environment. The thermal load required can be given by electric resistance heaters, evaporative heating procedure or, as in majority of applications, by coils through which a cool or warm fluid flows. The heat exchanger might be classified into direct or indirect typologies, according to the medium providing the heating or cooling effect:

    - Direct heat exchangers use the refrigerant fluid coming from a chiller or a heat pump during summer operation, while a warm fluid coming from the boiler can be utilised for the heating purpose.

- Indirect heat exchangers use water for both heating and cooling. In particular, in heating mode, hot water or steam is provided from the central heating generator, which can be a boiler or ATW heat pump; for cooling operation, the system requires liquid cold water from a chiller or an ATW heat pump.

If the AHU also dehumidifies the air, the water is over-cooled in order to create a surface temperature lower than the dew point. Doing so, excessive humidity is condensed. Furthermore, there is usually a re-heat coil after the cooling one in order to re-heat the air to the desired supply temperature. "This has the effect of reducing the relative humidity level of the supply air"[27].

- *Humidifier*: humidification is often required, especially in winter, where the air heating procedure can make the same drier, resulting in uncomfortable air quality that might cause irritation to throats.

- *Mixing chamber:* in many AHU's arrangement, exhaust and fresh air are mixed. This can be advantageous in both heating and cooling mode, since the mixing procedure can result in a natural and free cooling/heating. For instance, mixing the right amount of cooler external air with warmer return air can be useful to reach the desired supply air temperature.

- *Heat recovery device*: a heat recovery device can be applied between exhaust air and fresh one for energy savings and increasing capacity.

- *Blower-fan*: in most of applications, blowers with variable speed capacities are installed.

In summary, the air handler is a central unit where the air, after being filtered, is heated/cooled, humidified or dehumidified, and sent into the distribution system by a fan, finally reaching final emitters that enter the same into rooms. Therefore, the cooling operation of an AHU consists in a series of different actions, which start from a mixing procedure between exhaust and fresh air. The primary air so obtained is divided into two airflows; one of these passes through a refrigerant battery where it undergoes a process of dehumidification

[27] Wikipedia, Air handler

and cooling. The remaining flow rate bypasses the battery, then mixing with the airflow exiting from the same. The result is a cold airflow, not saturated but with high relative humidity. Finally, the primary air is post-heated in order to achieve the injecting condition required by the ambient. Therefore, it is evident that in cooling mode an AHU needs both a 'cold battery' and a heater. It is fundamental to underline that post-heating battery is powered by warm fluid taken from the refrigerant circuit. On the contrary, for the heating purpose, the fundamental elements are a pre-heater, a humidifier and a post-heater.

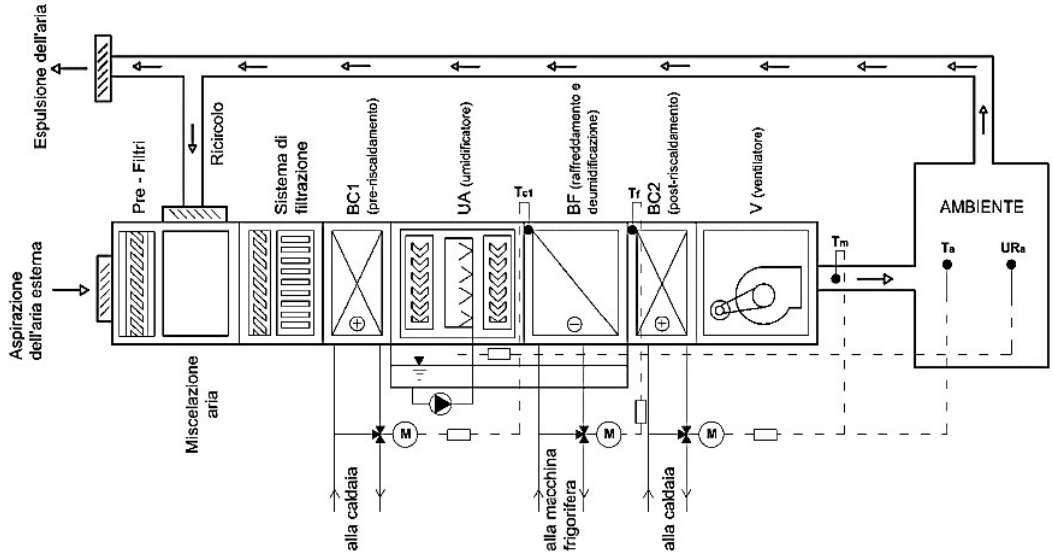


Figure 49 - Air Handling Unit (Source: Classificazione degli Impianti, slide Cinzia Buratti)

As previously stated, the air-handling unit has to be coupled with two or at least one generator, which has the duty to supply cold or warm fluid. Generically, a chiller and a boiler are used, but also a reversible heat pump can be applied for both operation in winter and summer. The fluid that passes through heat exchanger coils can be either water or refrigerant; the use of water is generically intended for applications that also include final emitters in which further sensitive cooling effect is provided to the room, as in the case of fan coil units. Some hydronic cooling systems require an AHU in order to control and regulate the latent load. The combination of AHUs with hydronic emitters, as fan coils and radiant panels, is design in order to achieve air ventilation and dehumidification on the airside, while to control the sensible thermal load on the waterside.

All air systems' regulation can be achieved by varying the supply air temperature or the airflow rate; according to the regulation typologies, these systems can be classified into two main categories.

1. *Constant Volume Systems (CV)*

   Constant volume air conditioning plants usually work with flow rates higher than necessary and therefore the energy transferred to rooms must be adjusted by acting on the temperature. Indeed, such systems are usually coupled with post-heating elements or final emitters, which ensure further sensible load's treatment. They are also described as low speed plants since the air velocity is usually around 10m/s. Constant volume systems can be further categorised:

   a. SINGLE DUCT

      It consists in a single duct from which different sections branch off for the conditioning of individual rooms.

   b. MULTIZONE

      The primary air is divided into parts, one addressed to the cold plenum, one for the warm one. Downstream the two plenum, there are many ducts as rooms to be conditioned. The same amount of air, which can be constituted by different portions of cold and hot air, is sent to each zone.

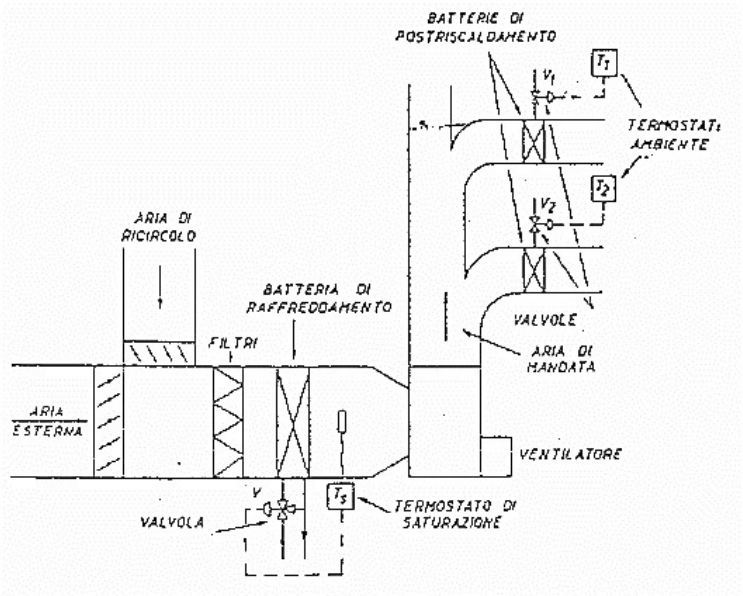


Figure 50 - Single Duct Configuration (Source: Classificazione degli Impianti, slide Cinzia Buratti)

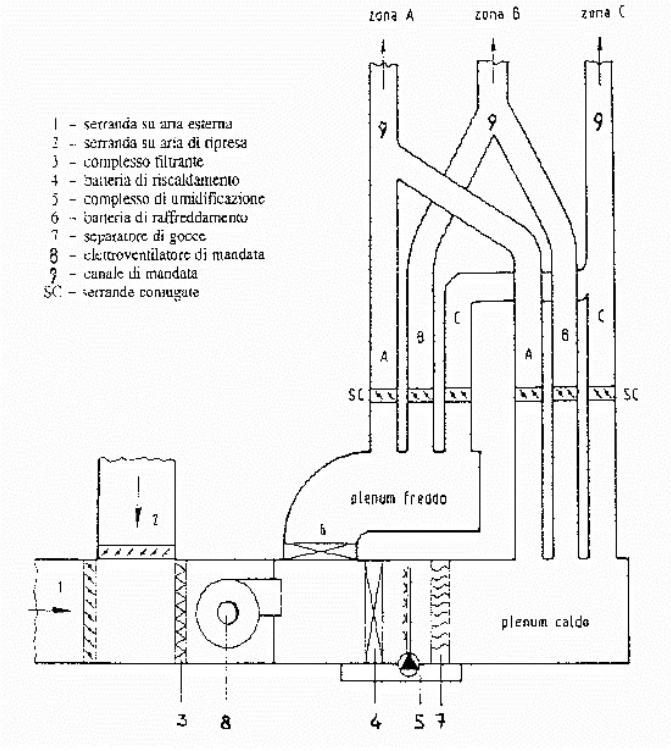


Figure 51 - Multizone Configuration (Source: Classificazione degli Impianti, slide Cinzia Buratti)

c. DUAL DUCTS

Dual-ducts system consists in a double distribution of warm and cold air in order to provide air with the desired setting in each room. Therefore, the plant is very similar to multizone configuration, but mixing occurs immediately next to rooms with cassettes controlled by thermostats.

The necessity to duplicate the distribution system also involves the need to reduce dimensions; the result of reducing the sections of ducts is an increase of air speed, whose rate is around 23-30 m/s. Therefore, these plants are characterized by higher noise and they are almost impossible for applications where the requirement of quietness is particularly important. The cold channel is crossed by air at a temperature of 10-15°C and at a rate equal to the sum of flow rates contemporary required from individual zones to meet the maximum cooling load. The flow rate of the warm channel is 50-75% of the cold channel's one. The two channels are combined in a box close to the room, where there is a low speed duct that serves terminal elements.

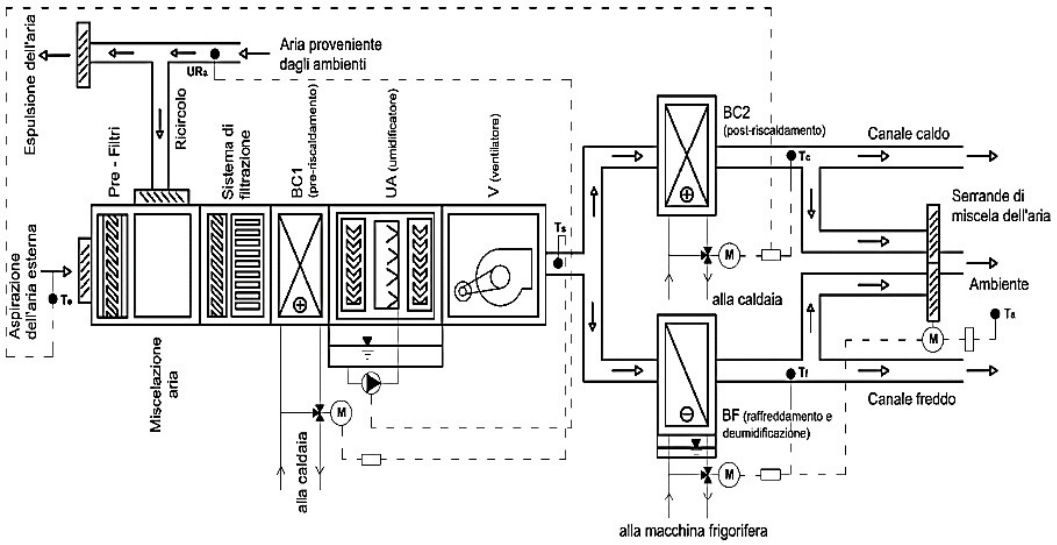


Figure 52 - Dual Duct Configuration (Source: Classificazione degli Impianti, slide Cinzia Buratti)

2. *Variable air volume (VAV)*

   VAV systems vary the quantity of air blown adapting the same to necessities of each room. The main advantage of VAV configuration deals with the elimination of post-heating batteries since the regulation of the airflow allows having a good control on the thermal load effectively required. Furthermore, the energy saving associated to fans and the elimination of double ducts are other two important aspects connected to VAV arrangement.

Although all-air systems are centralized and therefore are attractive for applications in multi-family buildings, it is evident that many peculiarities are restricting their use especially in the residential sector. First, entrusting the transport of sensible load to a working fluid, such as air, requires greater overall dimensions than those for a hydronic cooling system. On one hand, it is true that ducts are necessary to ensure proper ventilation; on the other side, however, it is more appropriate to assign the control of the latent load to the air plant and the sensible load's regulation to the hydronic one. The larger sizes due to the air distribution system present a greater impact on the dwelling's structure, in addition to higher installation costs. Moreover, to a greater footprint corresponds a greater difficulty of installation in existing buildings. Another consequence that would result from cooling by air as carrier fluid is the creation of cold streams that can be uncomfortable and cause inhomogeneous temperature distribution inside the room. In the end, running costs are higher due to ventilation and generators. AHUs' manufactures are improving all air system in terms of first costs, running costs, dimensions and noisy, and they are also developing plug-and-play units in order to facilitate and speed the installation of the same. Nevertheless, centralized all air systems can have strong applicability

in buildings that require precise hygienic, temperature and humidity conditions of the air, such as in hospitals and public edifices. Other advantages are related to the possibility of free cooling, of heating and cooling at the same time different areas, and to wide range of ventilation's flow rates available.

5.4.2 EVAPORATIVE COOLING

Evaporative cooling is a solution for summer air conditioning and it consists in the evaporation of a certain amount of water into the air. By evaporating water in an unsaturated with moisture airflow, it is possible to reduce the temperature of the same by increasing the quantity of vapour absorbed. It is immediately evident that such air conditioning alternative is strongly limited to applications in hot and dry climates. Indeed, in humid areas the main goal of an air conditioner is precisely connected to the reduction of humidity in the indoor environment since the same emphasizes the heat perception during warm seasons. Therefore, evaporative cooling has not significant chance of applicability in humid zones, such as the most cooling potential Mediterranean regions. Nevertheless, it is important to analyse such technology since it can play a significant role in dry areas, as well as give a great contribution in other cooling devices' development.

As affirmed by the International Institute of Refrigeration IIF, "the principle of evaporative cooling is based on the fact that the evaporation of a liquid absorbs significantly more heat that the amount required for its temperature to rise by a few degrees". Technologically speaking, there are three main configurations.

- *Direct evaporative cooling*

  The outdoor air passes through a component in which it enters in contact with water; this evaporates into the air making the same cooler and moister (see pathway 1). This process is also called as 'adiabatic cooling'. In hot and humid climates, with a process of direct evaporative cooling it is possible to reach saturation even with a small temperature's drop. Therefore, the cooling capacity in such areas is strongly limited.

- *Indirect evaporative cooling*

  A certain amount of water evaporates inside the exhaust air, which is then used in a heat exchanger in order to cool the fresh air. Therefore, the primary air is cooled down but the quantity of the water vapour in the same is unchanged.

Doing so, relative humidity increases while air temperature decreases, even if slower that in the direct cooling process (see pathway 2). This means that, in climates with hot temperature and high relative humidity, it is possible to obtain a larger drop of the former with a lower increase of the latter, compared to direct evaporative cooling configuration.

- *Two-stage systems*

  Two-stage arrangement combines direct and indirect evaporative cooling processes (see pathways 2 + 3). This procedure enables the temperature to decrease largely than when direct or indirect evaporative cooling is used alone. This solution is suitable just for arid areas.

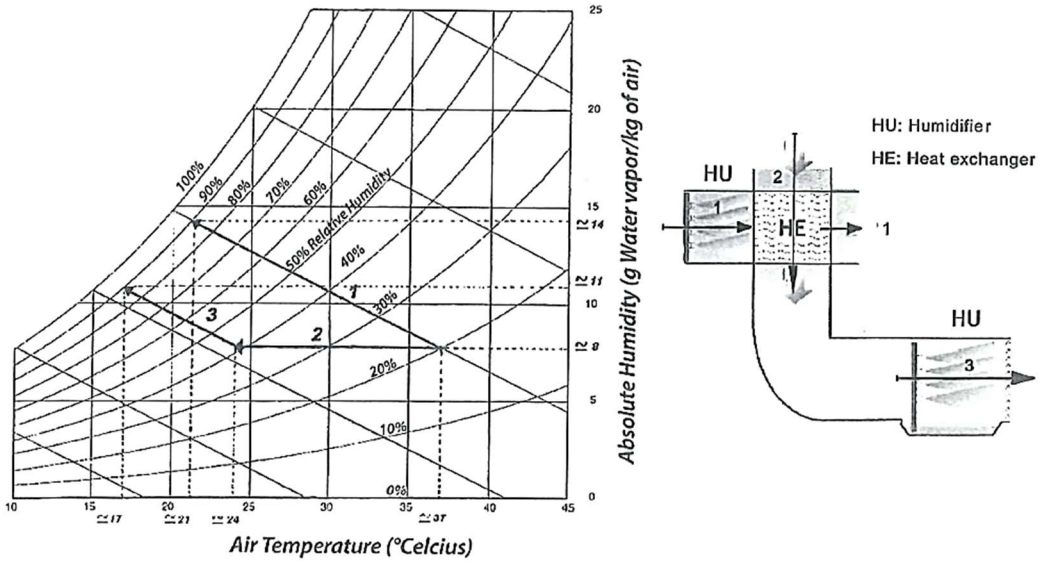


Figure 53 - Evaporative Cooling (Source: International Institute of Refrigeration – Institut International Du Froid)

Although according to IIF the evaporative technology gives a reduction of energy use and thus of operating costs, the same presents a fundamental problem concerning the water consumption. The water that evaporates is consumed, as well as the one used to avoid deposits of minerals. Furthermore, in many cases, the water has to be disinfected, filtrated and demineralized in order to fulfil hygienic and technical requisites. Hence, the evaporative cooling will make it hard to compete with other technologies so far analysed, even because climatic features of the warmer EU countries are not suitable for the operation of such systems. Nonetheless, as confirmed by the International Institute of Refrigeration, the evaporative solution might be implemented successfully in the condenser's cooling of traditional systems.

As described in *Heat Pump* paragraph, water can be evaporated in the condensation side of a heat pump; the decrease of the outdoor air temperature thanks to evaporative process would improve the heat pump's performance since the difference between indoor and outdoor conditions will be reduced. Another possible application deals with the implementation in desiccant cooling systems, following analysed.

5.4.3 SOLAR COOLING

The term 'solar cooling' indicates such technology according to which the energy of the sun is used for a building's air conditioning. As just stated, the use of both electrical and thermal energy produced by the sun for summer air conditioning is to be considered as solar cooling. Therefore, the following systems fall into this category:

- Heat pumps, especially in the configurations ATA and ATW, driven by the electricity produced with photovoltaic panels. Indeed, both split air conditioners and reversible heat pumps or chillers can operate thanks to solar electricity. Doing so, the operation of these systems becomes 100% renewable since they combined the use of natural thermal source such as external air and green electricity produced with PVs.
- Heat pumps driven by the thermal power produced with solar thermal collectors. Specifically, adsorption and absorption heat pumps can use a thermal input coming from the sun in order to operate and cool the indoor environment.

However, the configurations above have been already analysed as hydronic and split cooling systems; we talk about solar cooling only because the same are powered by solar energy. In reality, a particular air conditioning alternative uses solar power and this is not included in the previous categories: it is the desiccant evaporative cooling or, in the majority of cases, simply solar cooling. Desiccant cooling systems are a king of thermally driven plants, based on an air open circuit. Together with the use of heat coming from thermal solar collectors, another advantage concerns with the implementation of drying substances instead of refrigerants. Specifically, the plant consists into two air ducts in contact through two heat exchangers.

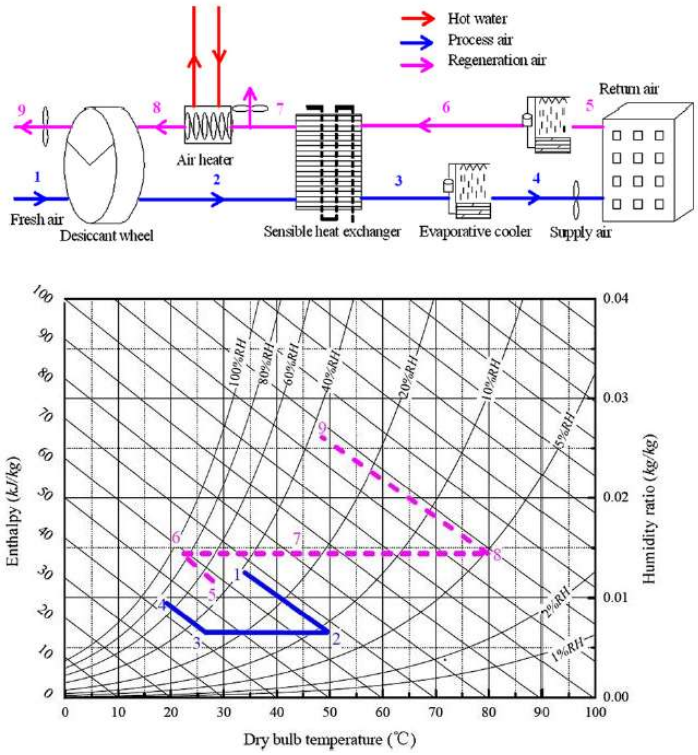


Figure 54 - Solar Cooling (Source: University notes)

12 – The outdoor air passes through a desiccant wheel, where it is cooled and dehumidified. The desiccant wheel is made by absorbent material and it is in contact alternately with the fresh air and the exhaust one. The absorbent material absorbs water vapour present in the outdoor air; this is why the latter decreases its humidity.

23 – The outdoor air passes through a sensible heat exchanger, where it reduces its own temperature without varying the humidity ratio. This process is also called 'sensible cooling'.

34 – Finally, the outdoor air passes through a direct evaporative cooler, which reduces further its temperature. The evaporative cooling procedure is more reduced as much humid is the external environment. After this final process, the air is released to the indoor ambient.

56 – The exhaust air passes through a direct evaporative cooler. This step is fundamental in order to achieve a higher humidity ratio. This is important since, given a certain temperature, the heat that the air must to absorb to reach a given relative humidity level increases with the humidity ratio.

67 – The exhaust air exchanges thermal power with the fresh one, heating itself.

78 – A further heating process for the exhaust air takes place thanks to a heat exchanger powered by hot water, heated by solar thermal collectors. The heating of the outgoing air is required in order to reduce the inlet air's relative humidity; in this way the former is able to absorb a greater quantity of water vapour from the fresh air.

89 – In the end, the exhaust air passes through the hygroscopic dehumidifier, which transfers the humidity absorbed from the fresh air into the outgoing airflow.

Some advantages and disadvantages can be identified talking about solar cooling. The strong advantage is connected to the overlap between the availability of solar radiation and the cooling demand. Furthermore, solar thermal collectors, which must to be installed for the desiccant plant, can be used also for the DHW, as well as for winter heating. Nevertheless, some limits are still present, mostly based on the poor knowledge of such solution. The present study thinks that the technology into consideration is too complex and less convenient compare to the use of solar electricity for powering other cooling systems. Moreover, installation costs are still strongly higher due to complexity and plant's dimensions. However, many are the rooms of improvements on the use of solar energy for summer air conditioning.

VI. European Market Report

6.1 Market Report Introduction

In the following sections a market report is developed. Cooling applications sales evolution is a tool, which can be helpful to have an overview on the cooling demand's changes and on the driven factors that have influences the same. In addition to this, a market analysis in terms of volume and value should highlight not only which have been the most common conditionings devices, but also how the products into consideration have covered the residential cooling load. Since many climatic, economic and cultural differences describe European Members, it has been decided to offer a global study of the key Countries[28], as well as a more detailed revision of some of them. Doing so, many aspects and criteria emerges and are the starting point for further considerations on the future probable market evolution.

Nevertheless, the lack of data, as well as discordances in terms of terminology, have had strong impact on the investigation. For instance, no information on the market are available in the period between 2005 and 2010. For years before 2005, BSRIA report for Europe[29] has been taken as the referent document, while, for the latest statistics, JARN journals[30] was used. Although they are two different references, BSRIA and JARN have collaborated in many reports about air conditioning market research. Therefore, the decision to work on both of these documents is valid since they base their studies on the same guideline. Furthermore, heavier difficulties emerge when one try to focus on the residential sector. Indeed, many market researches do not segment data into domestic and non-domestic sections, since there is no interest in doing so due to economic reasons for the investigation. However, as the present work has the goal to develop a study of tendency of cooling applications in housing, with a particular attention toward multi-family edifices, some assumptions have been necessary. Hence, the first step was to identify which are the most common applications used by households and to select so systems in the range of useful cooling capacity. The result of the mentioned phase was the identification of water-based cooling systems, RACs and PACs as solutions that should supply cooling effects in habitations. Specifically, coherently to the data available, the market report is firstly focusing on indoor air-cooling systems, in terms of RACs and PACs. The formers[31] are the products that chill the indoor air by carrying refrigerant

[28] Key Countries are Italy, Spain, Greece, Germany, France, UK, Russia, Turkey
[29] *BSRIA Report, World Market for Air Conditioning, Europe, April 2005 – Report 18768/1*
[30] *World Air Conditioner Market, May 25, 2012 and May 25, 2013*
[31] RACs (Room Air Conditioners)

fluid to terminals, room by room. This category includes window, moveable/portable and mini-split devices. On the contrary, with PACs[32] the present study takes into consideration indoor package, rooftop and ducted-splits, that is to say solutions that provide a centralized air treatment. In order to avoid misunderstandings, in the next table a comparison of terminology and a brief description are proposed. As one might recognize, a higher penetration by cooling devices in the commercial sector is recorded. A part from windows, which are products completely addressed to residential uses, moveable/portable, mini-splits and PACs sales are mainly for non-domestic applications. However, Greece, Spain and Italy are characterized by quite high diffusion[33] of air conditioning in houses; in other words, seals of the products last mentioned are strongly driven by households' demand too. This is the reason why, in order to figure out how much a technology is applied to dwellings, it is essential to develop a customized study for each of the main Countries selected. Only thanks to this approach, there will be the possibility to describe the trend of the residential cooling as part of the global indoor cooling demand in Europe and in the key EU Members.

Product type	Applications	USA Segmentation & nomenclature	Japanese Segmentation & nomenclature	Europe Segmentation & nomenclature
Window	Domestic/residential product	residential /light commercial unitary room units	Window RAC	Room self-contained
Moveables	Generally very small sizes (around 3 kW) but in Europe most sales are to non-residential applications. Negligible in USA	residential /light commercial (negligible market)	Regarded as a specialist category allied to RAC	Room self-contained
Minisplits/ ductless splits <5 kW/RAC split (almost all RAC split sales are below 5 kW)	Residential product sold via retail distribution in Japan, but apart from Spain and Greece, most are sold to the non-residential sector in Europe. Made in Asia often made in separate factories to PAC split	residential /light commercial unitary small market	Split RAC(1)	Split <5 kW
Minisplits/ ductless splits/ >5 kW/ PAC split (most PAC split sales above 5 kW and below 17 kW)	Product designed for non-residential applications and sold via the professional market in Japan. Some go into larger residential properties, but sales are primarily for non-residential applications. Includes Daikin VRV type products.	residential /light commercial unitary Very small market	Split PAC(1)	Split >5 kW
Ducted split (US type) (most sales below 17.5 kW)	In the USA nearly 4 million units are sold per annum, primarily for residential applications. Primarily found in North America only, practically non-existent in Asia and smaller Europe markets.	commercial unitary	Unitary (negligible market)	Large packaged (less than 20,000 units across Europe)
Single packaged /roof top (most sales below 17.5 kW in USA)	This is also non-residential and very small in Europe and Asia. In the USA, one million units are sold per annum, with some for residential applications.	commercial unitary	PAC (negligible market)	Large packaged
Indoor packaged	Rarely found in USA, generally non-residential in Europe.	commercial unitary	PAC	Large packaged

Figure 55 – Terminology (Source: BSRIA)

[32] PACs (Package Air Conditioners)
[33] Estimated penetration levels over 20%

6.2 Market Report

According to JARN estimates, in 2011 “the global market of air conditioners was about 96.7 million units”, that is to say an increase of 7.5% by 2010. Figure 56 underlines major contributors; it is evident that China represents the largest market and production base. It accounts for the 42.4% of the global market size and its trend is following a positive direction since many years. While the American, European and Japanese scenario are showing a phase of adjustment after the international financial crisis, the Chinese market has highlighted a strong solidity also through the economic downturn, although the year-on-year rate of growth slowed. Specifically speaking about the European development, Figure 56 shows that after 2009 the market size is slowly recovering. JARN supposes that 7.22 million of units are sold in 2012, which means that Europe accounts for the 7.5% of the global air conditioners’ market. The share of the European scenario is far from the contribution given by the others main markets, as the Chinese and American ones; this is the reason why Europe is deeply influenced by the latter. In other words, some chances in the Chinese and American air-conditioning market would have strong impacts in the European context. For instance, the great success that the split solution has experienced in Asia has been one of the main factors that have led the same to gain the dominant position in Europe through all cooling applications.

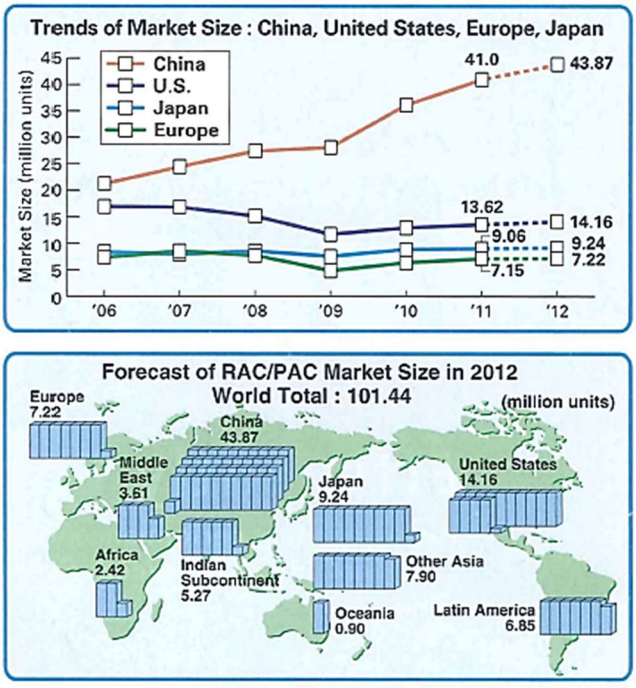


Figure 56 – Trends of Market Size (Source: JARN, May 25, 2012)

Beside the EU scenario describes a sluggish recovery, it is fundamental to underline internal discrepancies; if on one side Mediterranean Members have hugely reduced air conditioners' sales because of first saturation phase and huge economic recession, on the other side "the Russian market, however, continues to show strong expansion, and Turkey also posted satisfying growth"[34]. Another difference describes the market trends between the fist and the final years of the period analysed. A rough overview of the period within the scope of the present study shows a double market direction, positive at the beginning of the present millennium and negative after the international financial crisis.

6.2.1 AIR CONDITIONERS – EUROPEAN MARKET

First years of the new millennium were very proliferating for the European air conditioning market. The commercial sector has developed most rapidly and uniformly in Europe. It can be seen from the following table that the penetration of air conditioners is high in this category, over the threshold of 40%, in all European Members covered by the present study. On the other hand, the residential penetration of air conditioners is more diversified through the continent. Nevertheless, it is possible to recognize that Mediterranean Countries are characterized by a larger use of air-conditioning devices also in the residential sector, while Central Europe ones have a lower diffusion of the same. The main reason of such net distinction deals with climatic features. The market of the commercial segment is more advanced and evenly spread because it is tied more to the type of activities that take place inside the buildings than to climatic influences. On the contrary, the latter is the main stimulating factor for the residential category. Specifically, it is interesting to underline high values of the residential penetration in Greece and Spain; Italy is another contest in which residential summer air conditioning has reached significant results.

AC Penetration (2013)	Italy	Spain	Greece	France	UK	Germany
Residential	21%	44%	48%	9%	3%	3%
Commercial	44%	72%	55%	55%	42%	55%

Table 3 – Air Conditioning Penetration (Source: JARN)

As concerns unitary market, Europe is very small if compared with North America. Furthermore, lower attention has been reserved to centralized air conditioners. The main reason deals with the fact that, in Europe, these technologies are strongly installed for

[34] JARN, May 25, 2012

commercial buildings, as offices, supermarkets and hospitals and so they are out of the scope of the present study.

TOTAL EUROPE	Unitary market volume of outdoor units					BSRIA
	2003	2004	*2005*	*2006*	*2007*	*2008*
Rooftop	14912	16014	*16338*	*16926*	*17844*	*18834*
Indoor Packaged	43471	44236	*44447*	*45179*	*45955*	*46516*
Ducted-Splits	51350	54681	*55101*	*57268*	*59061*	*60882*
Grand Total	109733	114931	*115886*	*119373*	*122860*	*126232*

Table 4 – Unitary Market Volume (Source: BSRIA)

6.2.1.1 PRE-CRISIS AIR CONDITIONERS MARKET

Table 5 reports data about RAC outdoor units, for years 2003 – 2004 – 2005[35]. As previously stated, the same were characterized by a positive trend through the whole Continent. Specifically, all the technologies considered grew between 2003 and 2004 as consequence of a hot summer period between same years. Nevertheless, if on one side moveable devices and windows fell down, the market of mini-splits went on rising. In particular, the growth rate between 2003 and 2004 was about 26.5%; BSRIA evaluates that in 2005 mini-splits sales should be about 6.6 million[36] units in Europe.

TOTAL EUROPE						BSRIA
Residential/Light commercial market, volume of outdoor units						
	2003	2004	*2005*	*2006*	*2007*	*2008*
Moveables	491635	541420	*471886*	*479256*	*488546*	*498211*
Windows	216858	217438	*220590*	*241323*	*227968*	*214678*
Mini-splits	4780801	6046265	*6690321*	*7567707*	*8535156*	*9616420*
Grand Total	5489294	6805123	*7382797*	*8288286*	*9251670*	*10329309*

Table 5 – Residential/Light Commercial Market (Source: BSRIA)

The residential and light commercial segments are dominated by mini-splits, with a value of about 6.6 billion €[37]. The majority (70%)[38] are under 5kW, the typical capacity for residential applications. Furthermore, the 80% of these were in heat pump configuration, that

[35] Since the report for Europe was published in 2005 by BSRIA, data about years 2006 – 2007 – 2008 are estimations about sales, accordingly to the trend that was observed until that moment.
[36] BSRIA report 18768/1, 2005
[37] idem
[38] According to BSRIA study, approximately the 70% of the total mini-splits in 2004 are sold in smaller capacity

is to say reversible, for both winter and summer operation. Specifically, in 2008, the 78% of total sold products refers to single-splits and the 10% of multi-splits. The role of single-splits becomes more important since the application of the same account for the 80% of the cooling capacity installed[39]. Nevertheless, multi-type systems had improved their position in the market through the years. Reversible splits and multi-splits were applied for the 53% in domestic buildings; the only-cooling ones' portion was just 19%.

Moveable technology covered the 11% of the total kW installed in houses in 2008. This important contribution is mainly due to Italy, the European largest market[40]; however, in France, Germany and UK portable elements were the main air conditioning systems used in dwellings. One one hand the 56% of the moveable equipment market's value was relative to residential applications, on the other hand France, Germany and UK covered the 43% of the total amount of kW installed with the technology into consideration.

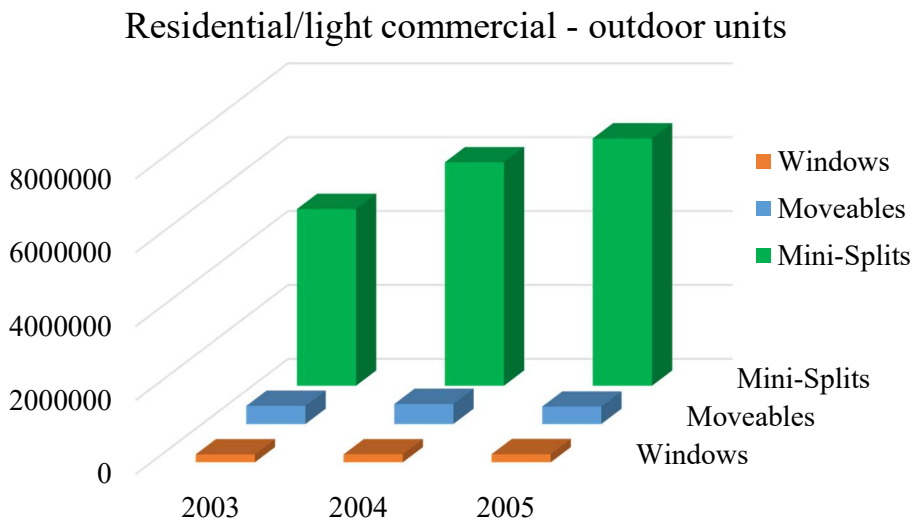


Figure 57 – Residential/Light Commercial Market (Source: BSRIA)

The structure of the market is strongly connected to the cooling demand's nature. Therefore, it is important to emphasize the connection between technologies and destinations of use. Specifically, RACs can be installed in new or existing edifices, as well as for substituting old products. According to the study conducted in 2008, over the 50% of units sold of moveable, single-split and multi-split configurations were applied in existing buildings; the 20-30% of the same were for new buildings, that is to say their installation was included

[39] Air Conditioners Final report of Task 2, December 2008 Economic and Market analysis
[40] *Air Conditioners Final report of Task 2, December 2008 Economic and Market analysis*: Italy, as mentioned, is the largest market for moveable products with the 43% of kW installed

in the habitation's design. This is an interesting result since it underlines the fact that households had privileged air conditioning systems' installation in a time subsequent to the construction of their own houses, as they did not perceive the same as essential but that can be added in case of need. At the same time, it is also a symptom of a young market and therefore intended for existing users. Different considerations are reserved for windows appliances; the 48% of the products sold are for replacements. This aspect confirms windows/through-the-wall equipment are solutions that principally base their market on the substitution of old same typology products, since they experience a huge competition by split and moveable solutions.

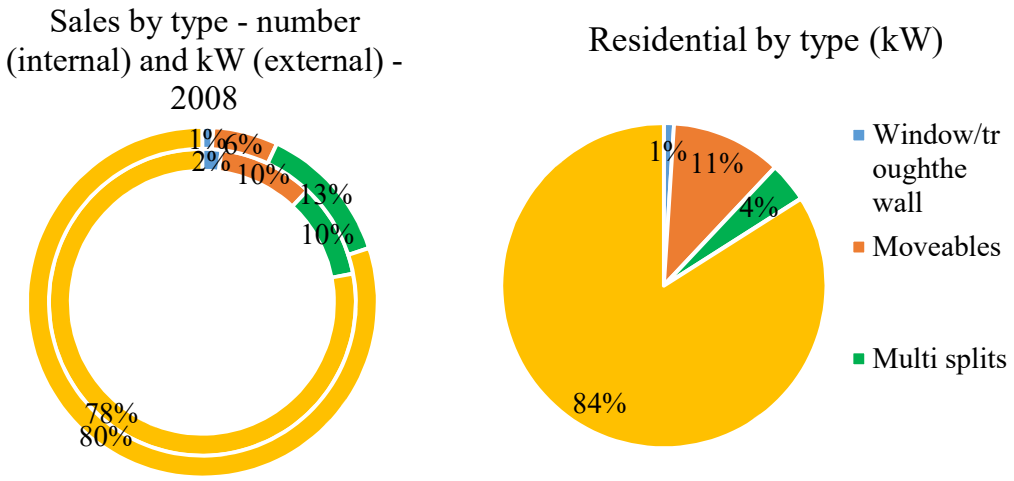


Figure 58 – Sales and Residential by Type (Source: Air Conditioners Final report of Task 2, December 2008)

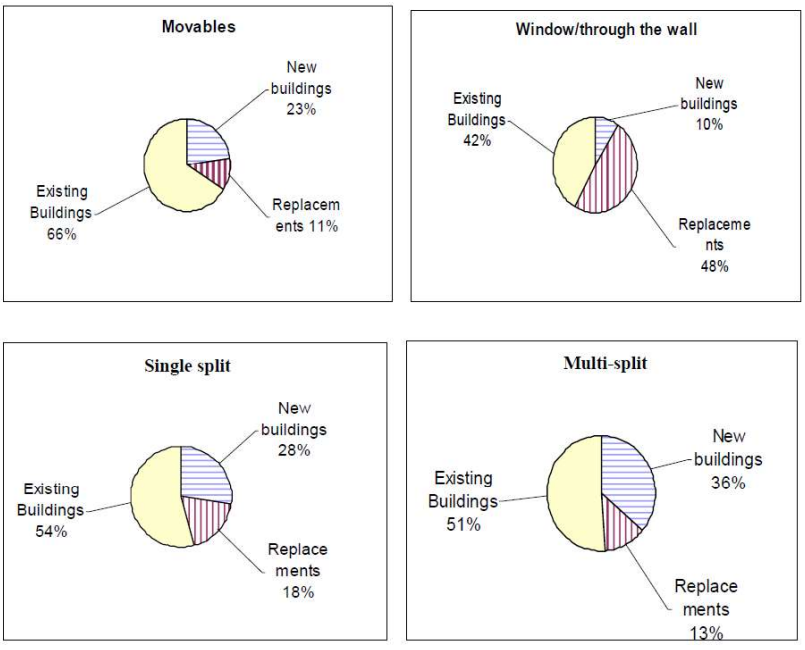


Figure 59 – Installation by Type (Source: Air Conditioners Final report of Task 2, December 2008)

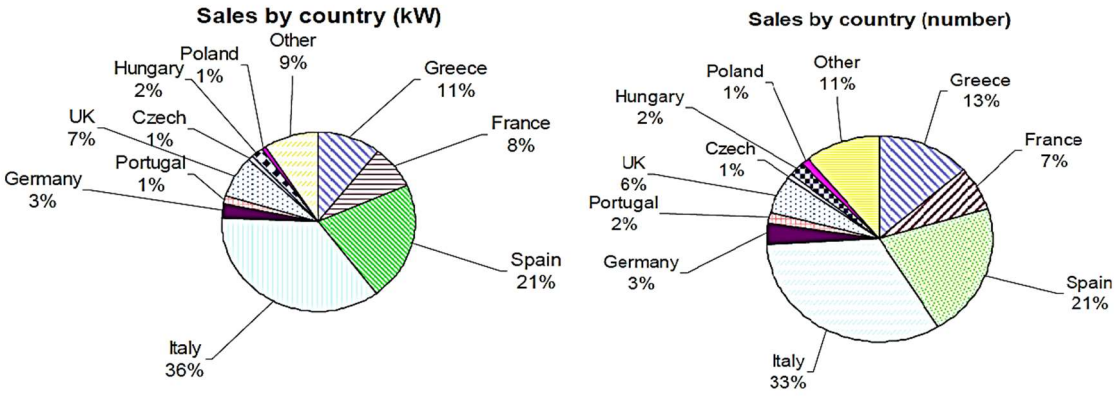


Figure 60 – Sales by Country kW (Source: Air Conditioners Final report of Task 2, December 2008)

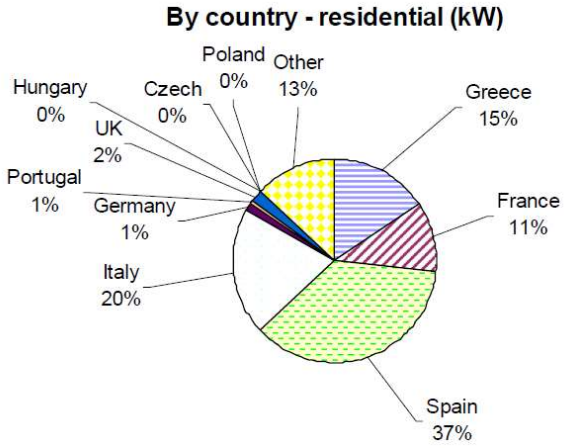


Figure 61 – By Country Residential kW (Source: Air Conditioners Final report of Task 2, December 2008)

The Mediterranean Countries covered the 67%[41] of the total market in terms of sales. Italy and Spain were the most significant Nations, for both sales and capacity installed. Focusing in a deeper way on the domestic category it is possible to identify Italy, Spain, France and Greece as the key Countries for the residential market in terms of kW installed. In particular, Spain accounted for the 37% in 2008, and together with the mentioned Countries, the values reached 83%[42].

6.2.1.2 POST-CRISIS AIR CONDITIONERS MARKET

[41] *Air Conditioners Final report of Task 2, December 2008 Economic and Market analysis* develops a market study of air conditioners, taking into account 12 kW as the limited capacity. In other words, the limit of 12kW eliminates most of the multi-room and centralized applications. That's why, there is correspondence between the products in the BSRIA's scope and the ones considered by Task 2

[42] Air Conditioners Final report of Task 2, December 2008 Economic and Market analysis

By reviewing period between 2010 and 2013, it is possible to compare two different market scenarios, before and after the international financial crisis. The analysis of market tendency of main six countries[43] shows that the European cooling demand grew rapidly in the years before the economic crisis, and, in particular, the contribution of split technology increased together with the growth of the global EU market. This was to detriment of moveable and window equipment, whose sales remained almost constant. On the contrary, the number of outdoor units sold by the key six EU Members dropped drastically after 2009 and since 2010 the trend of the air conditioning market have moved toward a negative profile. The reduction of total units sold between 2013 and 2004 was around -55%. The drop relative to mini-split units was similar to the global one, while the decrease of portable and window devices was respectively about -53% and -68%. Therefore, it is evident that the economic downturn have had a huge impact on the cooling market; negative consequences were recorded in both commercial and residential segments, as well as for all air conditioners. Specifically, the European bad situation has strongly damaged window equipment, which, because of also the huge competition of mini-splits, are going to disappear from manufactures' portfolios. Nowadays, economic repercussions are still present and the market is moving with diffidence and caution.

MAIN 6 COUNTRIES							BSRIA	JARN	
	2003	2004	*2005*	2009	2010	2011	2012	2013	Evolution 2004/2013
Moveables	387445	431098	*376428*		329500	243000	219000	201400	-53,28%
Windows	53900	50300	*50824*		27030	24000	17850	16200	-67,79%
Splits	3622472	4672519	*5075865*		2873233	2649231	2308100	2107250	-54,90%
Grand Total	4063817	5153917	*5503117*		3229763	2916231	2544950	2324850	-54,89%

Table 6 – Main Six Countries Market (Source: BSRIA and JARN)

Nevertheless, as previously affirms in the *European Market Report* introduction, there is a strong discrepancy in the European air conditioning market. Data from JARN journals describes a weak recovery and this is in contrast with what was stated just above. However, Figure 63 clarifies such doubt since it shows that the market size of the eight European Countries reported expanded in 2011 and it has remained almost stable in the coming years. This balance is given by the contrast between a negative trend in the main six Countries and a positive one in Turkey and Russia. Indeed, Turkey and Russia are two emerging cooling

[43] The advantage to focus the study on the key six European Countries concerns the simultaneous availability to have an overview of the European trend, as well as of the Nations' one, which are dominant in terms of market value and sales. Italy, Spain, Greece, Germany, France and UK accounted for the 79% and 76%, concerning respectively number of sales for moveable devices and mini-splits.

markets that are giving great contributions to the European one. Two results are significant: Russia is currently the fifth world air conditioner market and in 2013 Turkish mini-split sales were over the threshold of 1 million of units, that is to say just less of what done by Italy and Spain together. Italian and Spanish split technology's market have recorded a reduction of around -60% in terms of volume. On the contrary, together with positive performances of Turkish and Russian scenarios, it should be interesting to underline also the progressive trend of Germany, whose growth rate was around 61% between 2004 and 2013. Nevertheless, Germany remained the smallest mini-splits' market among those considered.

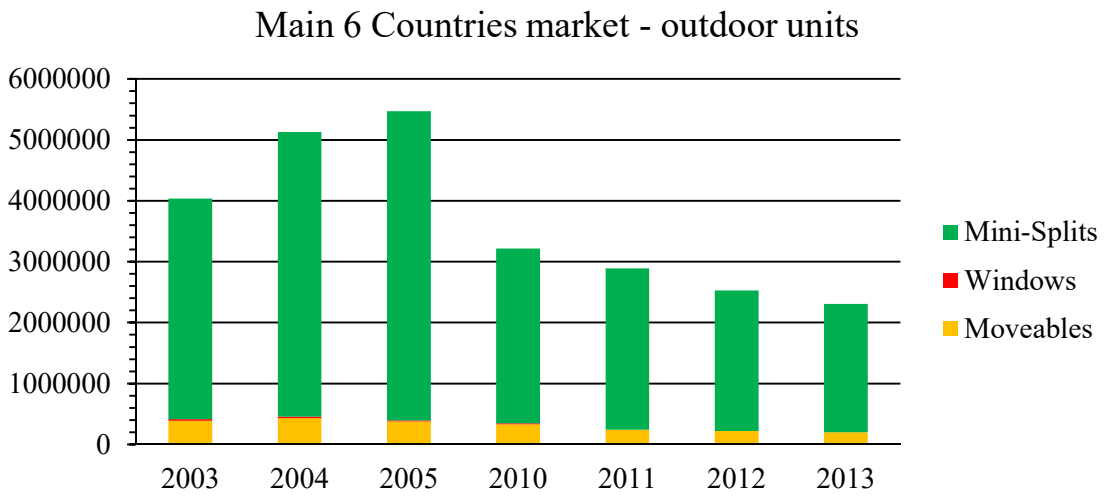


Figure 62 – Main Six Countries Market (Source: BRSIA Report – Europe and JARN 2012 – 2013)

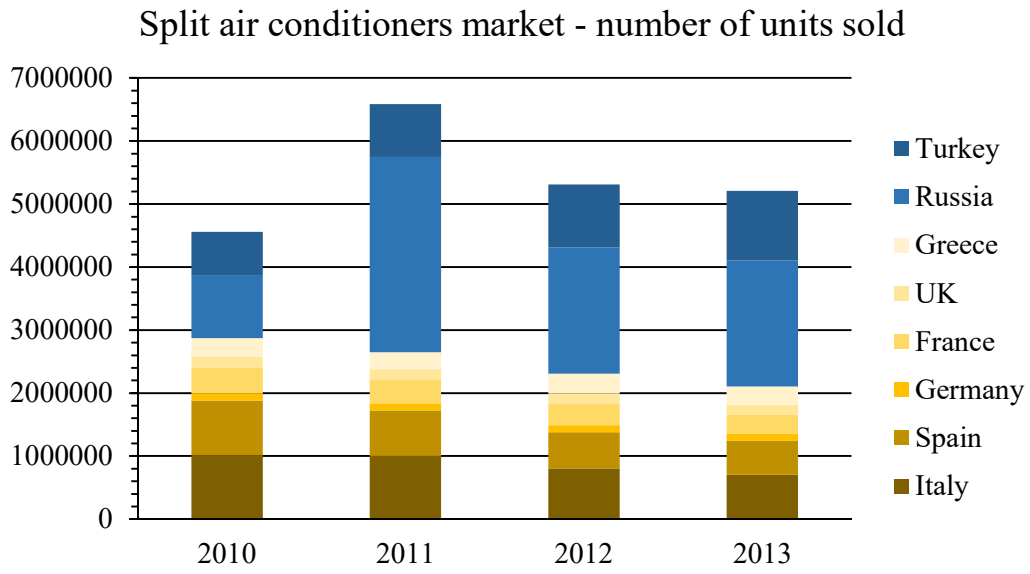


Figure 63 – Split Air Conditioners Market (Sources: BRSIA Report – Europe and JARN 2012 – 2013)

SPLITS SOLD	2004	2010	2011	2012	2013	Evolution 2004/2013
Italy	1916038	1010233	1000231	805100	703250	-63,30%
Spain	1389481	872000	722000	573000	539000	-61,21%
Germany	68000	116000	116000	110000	110000	61,76%
France	556900	400000	370000	335000	300000	-46,13%
UK	189573	175000	171000	168000	165000	-12,96%
Russia	350000	1000000	3100000	2000000	2000000	471,43%
Turkey	526321	688000	835000	1000000	1100000	109,00%
Greece	552527	300000	270000	317000	290000	-47,51%

Table 7 – Splits Sold (Source: BSRIA and JARN)

Looking in detail on split technology's market, it is possible to recognize that while single and multi-type splits dropped by -60% and -54% respectively, VRF configuration has experienced a great success also through the economic recession. Specifically, sales in the key six Countries, together with Turkey, increased by 55% in terms value between 2004 and 2013. This result confirms that the VRF arrangement has made a considerable quality and technological improvement speaking about split cooling applications. The great innovation of VRF systems has brought the same not only to mitigate the effects of the financial crisis, but also to increase their market position. In particular, they moved from covering the 9% of the total splits' market value in 2004 up to 29% of the same in 2013.

Split Market (million $)	2004	2013	Evolution 2004/2013
Single-split	4170,3	1631,9	-60,87%
Multi-split	1100,3	504,2	-54,17%
VRF	552,5	856,5	55,02%
Total	5823,1	2992,7	-48,61%

Table 8 – Split Market (Source: BSRIA and JARN)

The growth of VRF systems has not been uniform in Europe; unlike other European Members considered, Spain and Greece reduced their VRFs' value, confirming the heavy impact of the economic downturn on the same. Together with the special Turkish case, Italy, Germany and France gave significant contributions to the VRFs' market development; in 2013, the latter three countries accounted for the 52% of the total VRFs' market value of the seven European Nations into analysis. UK grew only by 38%, but it is the largest European market in terms of VRF applications.

VRF	Italy		Spain		Germany		France		UK		Greece		Turkey	
	2004	2013	2004	2013	2004	2013	2004	2013	2004	2013	2004	2013	2004	2013
Million $	84,5	192	116,6	57	67	156	57,5	180	173,7	240	53,2	31,5	12,4	149,6
Evolution	127,22%		-51,11%		132,84%		213,04%		38,17%		-40,79%		1106,45%	

Table 9 – VRF Market (Source: BSRIA and JARN)

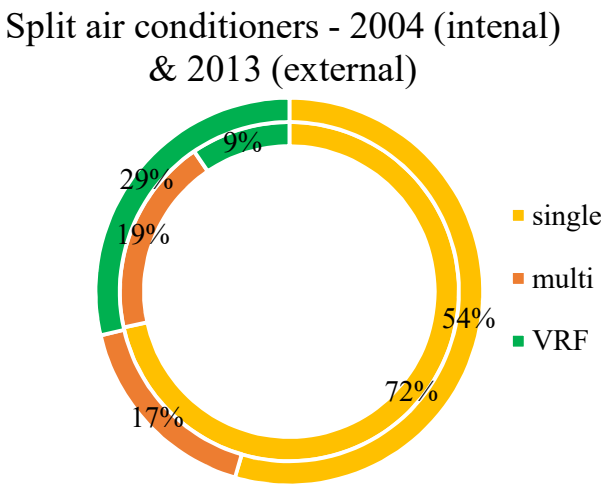


Figure 64 – Split Air Conditioners 2004 and 2013 (Sources: BRSIA Report – Europe and JARN 2012 – 2013)

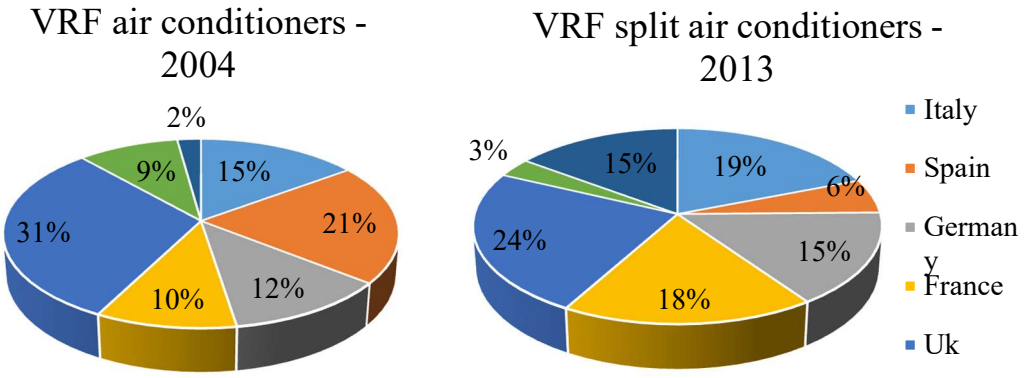


Figure 65 – VRF Evolution 2004 and 2013 (Sources: BRSIA Report – Europe and JARN 2012 – 2013)

6.2.2 HEAT PUMPS and HYDRONIC COOLING – EUROPEAN MARKET

In the present chapter, it has been decided to analyse the market of hydronic cooling systems through the one of chillers, or in general reversible heat pumps. Precisely, on one hand with residential hydronic cooling we mean especially the use of FCUs and radiant panels as final elements, while, on the other hand, the attention is directed to reversible heat pumps and chillers since they are the most common generators hydronic application. In addition, it is clear that ATW and GSHP configurations are mostly under examination, because they are generators that transfer thermal power to water in order to achieve space heating or cooling. This choice has been dictated by the lack of data about final elements and this is the reason why it has been established to move the attention toward heating/cooling generators. Although

the difference between the products, this way of study is anyway sufficient to figure out the role and trend of hydronic cooling systems.

UFH Million meters	Italy	Spain	Germany	France	UK	Russia	Sweden
2013	60.000.000	15.000.000	98.000.000	50.000.000	30.000.000	35.500.000	16.000.000
Share	19,70%	4,93%	32,18%	16,42%	9,85%	11,66%	5,25%

Table 10 – UFH Million Meters (Source: BSRIA)

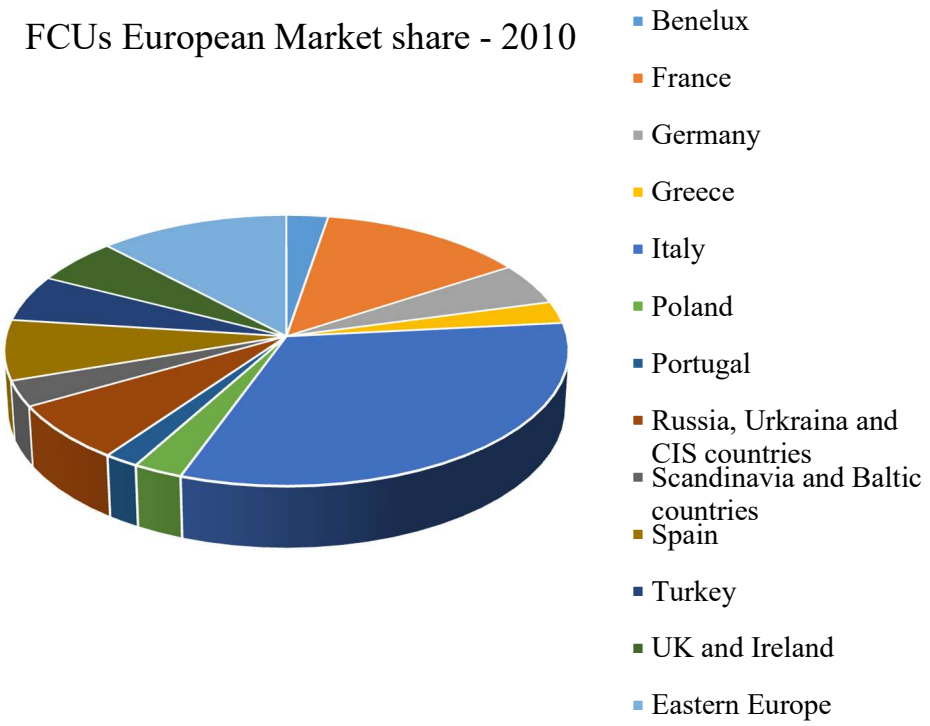


Figure 66 – Fan Coils Market (Source: Eurovent Market Intelligence)

FCUs - market by countries in 2010

Countriest	Units sold	Share
Benelux	33725	2,64%
France	168028	13,17%
Germany	63256	4,96%
Greece	33292	2,61%
Italy	409830	32,13%
Poland	32987	2,59%
Portugal	22957	1,80%
Russia, Ukraina and CIS countries	87054	6,82%
Scandinavia and Baltic countries	39124	3,07%
Spain	91575	7,18%
Turkey	70682	5,54%

UK and Ireland	69169	5,42%
Eastern Europe	153847	12,06%

Table 11 – FUCs Market (Source: Eurovent Market Intelligence)

Nevertheless, the analysis takes into consideration all types of heat pumps, but for the reason explained before, more attentions are dedicated to reversible ATW and GSHP. The scope of these considerations is to understand which is the heat pumps' trend as renewable alternatives, for both cooling and heating, and which are the main factors that could influence a further penetration of the same in the market.

Heat pumps for space and water heating in the residential sector are gradually gaining market traction in Europe since some years, because they are perceived as one of the most efficient and green alternative solutions for the same purpose. It is true that the predominant position of traditional heating systems is still present, but heat pumps have to be considered in a view of renewable future and reduction emission from the domestic segment. They are products that uses electricity in order to move thermal power from a warm source into a cold sink and it is demonstrated that the energy consumed by the system into consideration is lower if compared to the one burned by a conventional heating source. When we speak about renewable sources, it is clear that the energy's form that follows is the electric one; it is difficult to obtain from wind, water and solar power the thermal supply necessary for the homes' energy demand. As a consequence of what just said, many of the residential systems, from appliances, controls to space heating/cooling plants are developing in order to be able to use renewable electricity from the net or produced in loco (PV). The heat pump, therefore, is a solution, which ensures energy saving and, at the same time, renewable energy use if combined with PV or thermal solar panels too. Up to now, heat pumps together with solar systems are the only way to fulfil thermal demand in habitations through renewable sources. This is the reason why heat pumps are expected to obtain a significant reputation on the market as green-alternative to the traditional boilers and domestic cooling plants. Nevertheless, the success of the equipment in analysis has been slowed down by many factor, probably by most economical reasons such us the lack of subsidies and the falling price of crude oil. In particular, in 2011 heat pump sales come to over 770,000 units, of which 170,000 and 108,500 units were respectively on the ATW and GSHP configurations. According to JARN, while air conditioners' market has experienced a strong impact due to the international financial crisis, the ATW's one "maintained its scale year on year in 2011 and shows long-term growth potential"[44].

[44] JARN, August 25, 2012

Significant contributions are recognizable in France (55,300 units), Germany (32,600 units) and UK (14,900 units).

From both pictures below, one might recognize that the main renewable source is the air in the European market (85%), and, in particular, the segment is dominated by air/air configuration, as well as air/water units (ATW). It is fundamental to underline that *European Heat Pump Market and Statistics Report 2013* considers ATA heat pumps as split units, the purpose of which is mainly related to heating. Therefore, ATA sales are supposed to be just one part of the global amount of reversible split units sold, that is to say they are the ones installed mainly for supply heating.

Aerothermal units are used in warmer climates where they can also be used for cooling, while colder climates demand a more stable source temperature and thus lead to a larger share of ground-coupled units. It is evident the difference between the share of air-source and ground-source heat pumps in countries like Italy, Spain and Poland, Netherlands. Moreover, while the air-source market is supposed to be able to expand further, according to EHPA (*European Heat Pump Association*) the numbers of ground-coupled systems sold is expected to remain stable in the following years and their share should become lower.

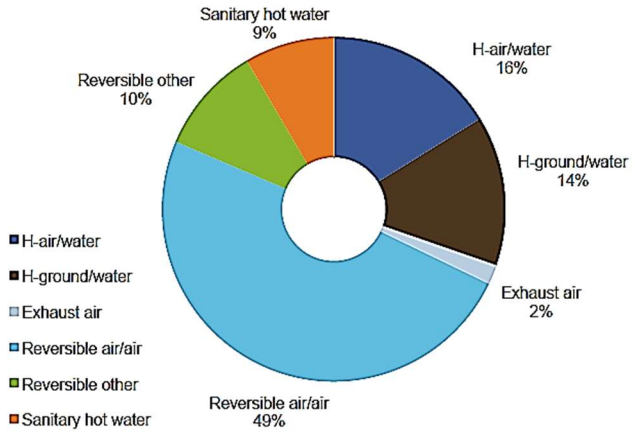


Figure 67 – European Heat Pump Market (Source: European Heat Pump Market and Statistics Report 2013)

Heat Pumps (2012)	Italy	Spain	Germany	France	UK	Sweden	Finland	Norway	Denmark	Total
ATW	12801	1374	37400	54214	14455	6384	979	2806	2113	130413
WTW	1311	511	2800	1295	0	18				5935
GSHP	408		16800	3593	2294	24502	12953	3211	3072	63761
ATA	104685	48251	0	31709	1050	55000	44956	60959	21635	346610
Total	119205	50136	57000	90811	17799	85904	58888	66976	26820	546719

Table 12 – Heat Pump Market (Source: European Heat Pump Market and Statistics Report 2013)

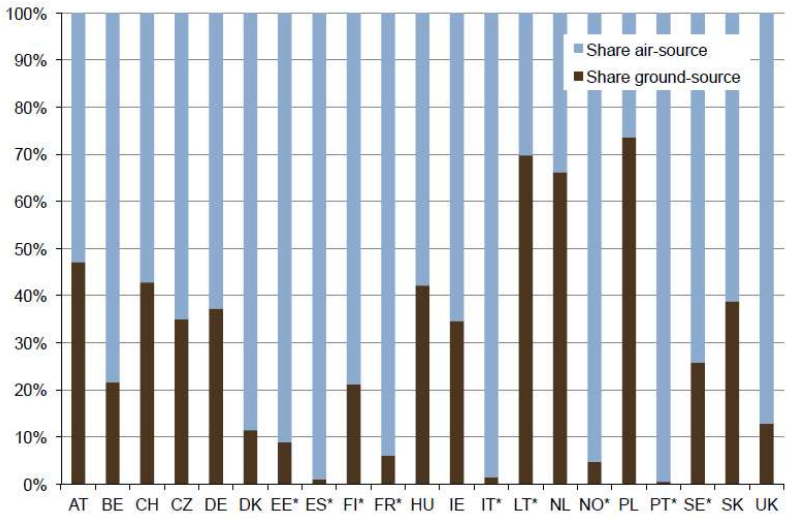


Figure 68 – Share Air Source and Ground Source (Source: European Heat Pump Market and Statistics Report 2013)

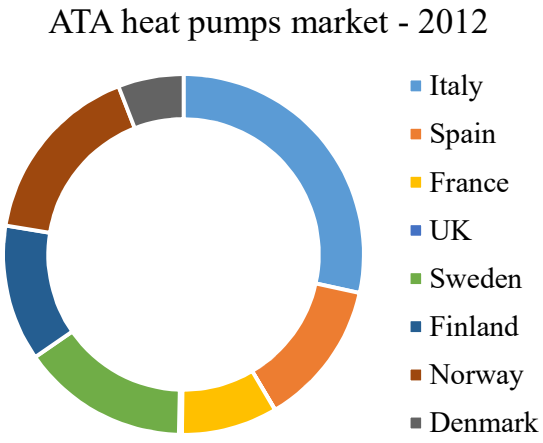


Figure 69 – ATA Heat Pump Market (Source: European Heat Pump Market and Statistics Report 2013)

In the previous table, there is the number of units sold concerning the most important European countries within the scope of the present study. First, it is important to underline the strong positions covered by Italy, Spain, Finland, Norway and Sweden regarding air-air systems with heating function. As concerns Spain and Italy, it is clear that the high penetration of air conditioners has a deep relation with their role for heating purpose too. Specifically, according to International Heat Pump Association, in Italy the 9.5% of the reversible air conditioners' amount is connected to the main heating function; in the Nordic regions of the Country, for the 50% of the cases these products are effectively used for space heating, while the share is just around 10% for Southern areas. Spanish and Italian populations have a strong predisposition toward reversible aerothermal solutions since both heating and cooling are relevant through the year. Different reflections are relative to mentioned Nordic Countries,

where it is evident that the market demand of ATA heat pumps is hugely dependent on space heating requirements. What obtained is an important results; the marked demand of ATA heat pumps for main heating purpose is more or less the same if we consider together on one hand Nordic Countries (Finland, Sweden and Norway) and on the other hand Mediterranean ones (Italy and Spain).

Speaking about ATW and Brine-Water heat pumps (ground source heat pumps), the most important EU Members are Germany, France, Finland and Sweden. Specifically, Central Europe regions play the fundamental role (near 70%) concerning ATW configuration; UK, Italy and Sweden give an important contribution to this market. In order to be more specific, German, French, English and Italian ATW sales in 2012 were respectively of 37.400, 54.214, 14.455 and 12.801 units. On the contrary, Nordic European Countries, such as Finland and Sweden, and Germany dominate the GSHP market.

However, it is interesting to underline the close connection between the heat pumps' market dimension and the one concerning FCUs and radiant panels. For instance, Italy and France are the largest market in Europe concerning FCUs and significant ones for radiant panels; at the same time, they are both fundamental realities in the European ATW's scenario. Likewise, Germany is consistent for both ATW and GSHP; moreover, Germany is the most relevant market analysed regarding hydronic radiant heating. Therefore, it is evident that hydronic heat pumps and hydronic final emitters follow the same trend. Consequently, the European Countries playing a central role in the hydronic heat pumps' market are also supposed to be the main protagonists regarding hydronic air-cooling.

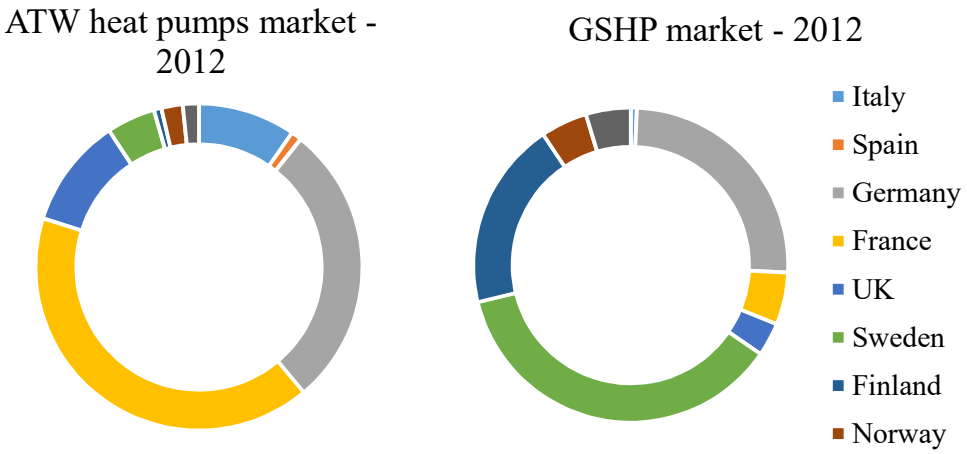


Figure 70 – ATW and GSHP Market (Source: European Heat Pump Market and Statistics Report 2013)

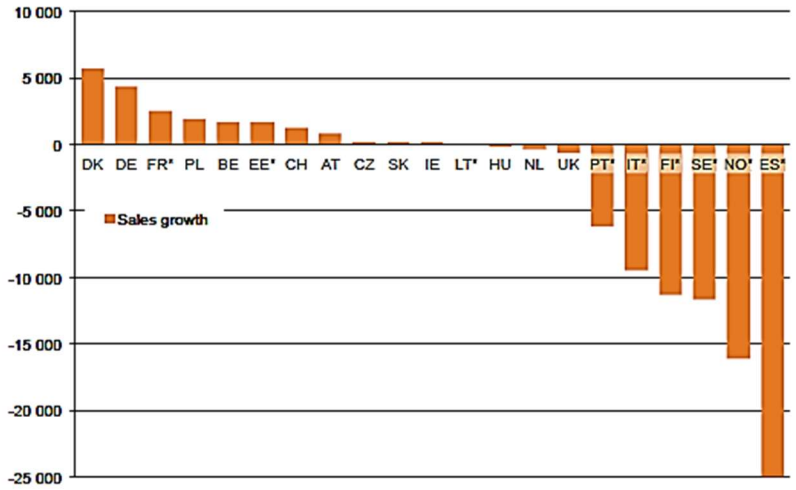


Figure 71 – HP Market Evolution 2011-2012 (Source: European Heat Pump Market and Statistics Report 2013)

Nevertheless, if on one side Denmark, Germany[45] and France has experienced a good trend between years 2011 and 2012, on the other side there was a huge reduction in sale in some fundamental Nations as Spain, Italy, Finland, Sweden and Norway. Several are the reasons of this drop; if for Italy and Spain the economic crisis has had a strong impact on the national markets, for the Nordic Countries we have to take into consideration the important influence due to market maturity. Indeed, Nordic States have been characterized by high development of heat pumps for residential applications since many years and it is clear, as confirms JARN, that the same have reached the first stage of saturation. Despite the stagnant Finnish and Swedish markets, "heat pumps are still the preferred choice in new construction as well as for retrofitting the existing building stock"; the 50% of the Swedish single-family houses are equipped with heat pumps and an ascendant tendency is influencing also multi-units edifices. The most important driven factor is that Finish and Swedish authorities have recognized heat pumps as a fundamental technology in order to pursue environmental targets in the residential sector and this is the reason why Nordic governments have developed several subsidies' schemes in order to promote the diffusion of these systems as substitution of old common heating plants. However, nowadays the Nordic Countries are symbol of a general trend toward GSHP; on the contrary, in the other EU Members the increasing inclination for ATW heat pumps is consistent. In conclusion, the current low penetration in the European market makes heat pumps to have a large growth potential, since mass markets have not yet been established. ATW heat pumps' high expectations are especially supposed for countries like Germany, France and Italy.

[45] In Germany, it is emphasized the trend of an increasing market share for ATW heat pumps, as well as in France

Although the positive forecasts, ATW and GSHP heat pumps have concretely experienced a huge difficulty to enter the space heating/cooling market since costumers perceive hydronic heat pumps as a more expensive solution if compared with traditional boilers and this is true in terms of initial investment. Investors are more often driven by short-term focus on investment cost only, ignoring the total cost of ownership perspective. The current success of traditional plants is related to the low initial price, while the merit of alternative solutions as heat pumps is connected to money saving due to lower energy consumptions during operating lifetime. In this contest, it is evident the role that governments and national authorities have to play with incentives in order to make renewable sources more competitive, but the lack of sufficient subsidies' scheme has limited, as a consequence, the spreading of hydronic heat pumps in the domestic segment. To make matters worse, one should also take into consideration the rising electricity's prices. It means that if in the past "a TCO[46] perspective revealed a cost advantage for heat pumps due to much lower operating cost", nowadays "this advantage shrunk significantly as a result of a parallel reduction of fuel prices and an increasing electricity cost"[47]. Hence, it is evident that heat pump is not an alternative solution that should be sponsored as green and economical anymore and it might be hard in the next decade to promote the same because it is the premium product or for its environmental friendliness. In addition to that, manufactures need to develop the technology by reducing costs, in order to make the product more affordable for clients.

	AT	BE	DE	EE*	ES*	FI*	FR*	HU	IE	IT*	PL	PT*	SE*	SK	UK
HP | oil	2,41	2,88	3,43	1,14		1,27	1,68	2,85	2,46		1,76	2,21	0,97		3,14
HP | gas	3,05	3,06	4,53		1,81	1,81	2,08	3,78	3,24	3,67	2,78	3,11	1,23	3,22	4,44
HP | DH	2,14		3,52	1,51		1,59	1,95	3,20			1,88		1,29	2,38	
HP | pellets	3,85			2,12		2,60	2,54	8,00	4,45		2,50	2,58	1,94	4,14	4,00

Table 13 – Energy Price Ratio (Source: European Heat Pump Market and Statistics 2013)

The aspect explained above is further highlighted by the *energy price ratio* (EPR); this parameter is the ratio between the price of electricity and the price of 1kWh of useful heating energy delivered by the competing technologies. In particular, a heat pump system has a comparative advantage over competing technologies whenever the seasonal performance factor in the location of application is higher that the EPR. According to this perspective, Germany, Italy and UK seem to be Countries in which the economic advantage of heat pumps is absent; on the contrary, France, as well as Spain, Finland and Sweden, presents a low *energy*

[46] TCO = total cost ownership
[47] *European Heat Pump Market and Statistics 2013*

price ratio and the installations of heat pumps should concretely lead to both energy and money saving[48].

6.2.3 NATIONAL STUDY

In the following sections, a study of selected Countries has been developed, focusing on different items. Specifically, the present study wants to underline different market development according to different climatic zones:

- Italy and Spain for the Mediterranean area
- France, Germany and UK for central Europe
- Norway, Sweden, Finland and Denmark for Scandinavia
- Russia and Turkey as emerging countries in the cooling market

National descriptions of the residential building contest has been proposed in order to have a clear overview on the buildings stock and on the residential construction industry prospective. In the end, the reader should find an examination of which have been the main air-cooling technologies adopted by households, as well as considerations on which have been the main guide factors that have driven national residential cooling market. Furthermore, it has been decided to report final opinions on how national markets should develop in the following few years and which might be the roles of different cooling applications.

[48] Price energy ratio for 15 EU Countries

ITALIAN CASE

Italy represents one of the most important European Member in the topic into consideration, since climatic conditions during summers are what have driven a huge cooling demand during past decades. As visible in Figure 72, the domestic segment plays a relevant role in the national total floor area. In addition to that, it is useful to say that residential construction was the largest market with the 58%[49] of the construction industry's value in 2014. In particular, the stock of multi-family dwellings is very important since it accounts about the 80% of both the total residential number of habitations and floor area[50].

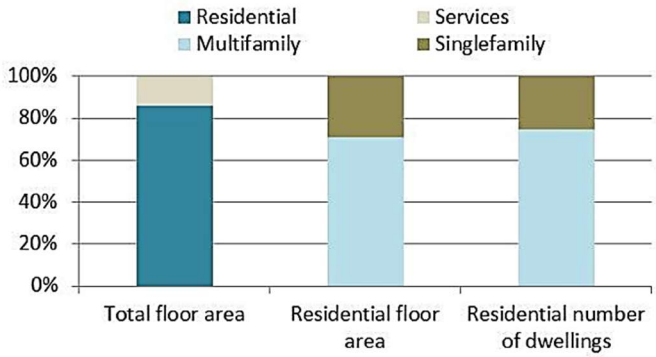


Figure 72 – Italian Total Floor Area (Source: ENTRANZE)

In order to be precise, even if one has to consider the difficult to find updated data, the share of multi-family dwellings in 2009 was about 54.9%, while the one that concerns high-rise dwellings was around 23% in 2004. Hence, multi-family houses are a significant part of the total residential buildings' stock in Italy, since it accounts about the 78%. Thanks to statistics coming from the last census[51], the following data are available:

- Total number of residential edifices = 11.720.482
- Total number of dwellings = 29.074.722
- Average dwelling size = 99m^2

Focusing on the domestic sector, with a particular attention to multi-family edifices, the typology of the national construction industry is classified due to the climatic zones, the

[49] CIC, Construction in Italy – key trend and opportunities to 2019
[50] *ENTRANZE*; data refer to the decomposition of buildings by type in 2008
[51] Census of 2011

age and the characteristics of the structure. In Italy, there are three main climatic zones, which are:

- *Area climatica media*
- *Area climatica alpina*
- *Area climatica mediterranea costiera*

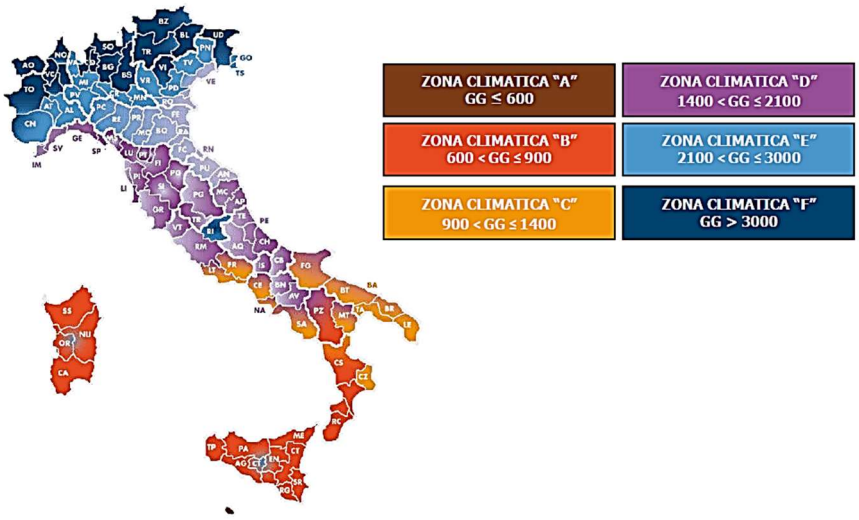


Figure 73 – Italian Climate (Source: Building typology brochure – Italy, July 2014)

The *Area climatica media* is the one that represents most common climatic conditions in the Nation. Furthermore, it is the most representative one also because in the climatic zone E[52] there are included 4250 municipalities, that is to say the 52% of the total. Nevertheless, since the scope is the analysis of applications for cooling, the *Area climatica mediterranea costiera* (the one in red) is significant since describes regions with hot summers and high solar irradiation.

Figure 74 shows the number of built residences, highlighting the period of construction and the number of dwellings in the edifice. A deep increase in the construction industry has been recovered after the Second World War, reaching its top in the period between 1962 and 1971. The same figure underlines the importance of multi-family buildings and stresses the position of existing edifices, since this lead many influenced both in the residential energy saving policy and in the indoor air-cooling market.

[52] According to D.P.R. n 412/1993 Italy is divided into six climatic zones (from A to F) due to the number of heating degree days. *Area climatica media* includes the climatic zone E, the *area climatica alpina* includes climatic zone F, while *area climatica mediterranea costiera* includes climatic zones A, B and C

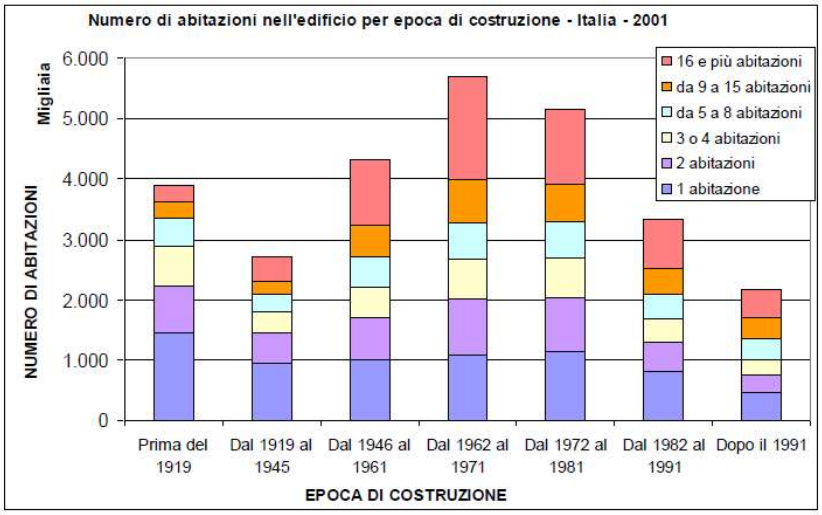


Figure 74 – Italian Construction Period (Source: Building typology brochure – Italy, July 2014)

A part from the negative trend following the decade 1962-1971, another strong reduction has been recovered in the past ten years, mostly due to economy's contraction. Now there are no positive forecast for the future; together with economic recovery, the construction industry hopes that factors as the rising population, as well as urbanization[53], might inspire new demand for the domestic construction. As confirmed by Figure 75, the market is supposed to a forecast CAGR[54] of 0.50% in 2019. It is also evident that multi-family housing recorded on one side a higher reduction than single-family housing, and, on the other side, its forecast is less optimistic. Nevertheless, in 2013 multi-family housing recorded outputs, which were larger if compared to the single-family ones.

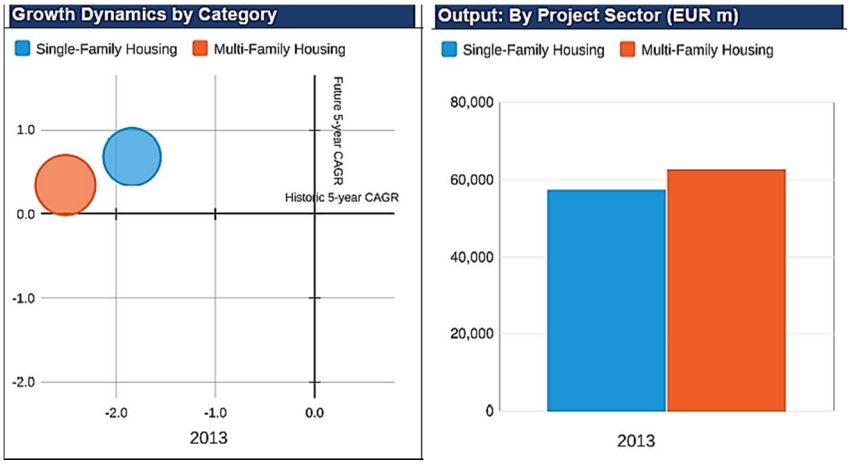


Figure 75 – Italian Construction Industry (Source: CIC, Construction in Italy – key trend and opportunities to 2019)

[53] 61.4 million people are expected in 2020. Italy's urban population increased from 67.2% of the total in 2000 to 68.9% in 2010. Estimation says that it will reach 69.8% in the 2020, and 70.4% in 2030.
[54] CAGR = compound annual growth rate

Italy is one of the largest markets as concerns air conditioners. Both commercial and residential sectors are involved; in particular, for the former the penetration was around 44% in 2012, while for the latter it was close to 21%[55] in the same year. This means that 604 million of m^2 are equipped with air-conditioning devices, as confirm of the huge demand for cooling in the Nation, and 2 billion m^2 are still not furnished. The Italian market had a strong grew in the past 15 years since air conditioners were not perceived as a luxury, but as a necessity. The necessity to face up very hot summers, as well as also very moist ones, have pushed citizens to buy many air-cooling systems, so that they started to think about these devices as normal domestic appliances. It is also clear that, as the main factor has been necessity and not luxury, costumers have preferred economic solutions. Although the market still associates the Asiatic brands with low quality products, the affordable prices of the Asian manufactured systems has convinced an increasing share of consumers to purchase. Nevertheless, Italian manufactures cover an important role in the domestic market, mostly for moveable equipment and chillers.

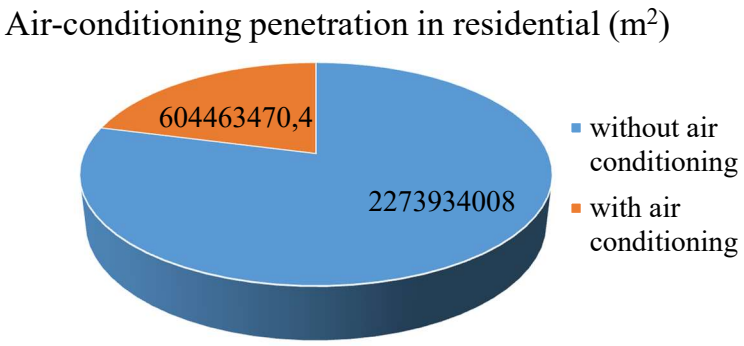


Figure 76 – Italian Air Conditioning Penetration (Source: JARN, May 25, 2013)

Many are the factors that might have influenced the indoor air-cooling trend in Italy. The tendency of mini-splits sales is quite symbolic in this case; even if split solutions are the most common ones inside the Country, they have a decrease of -68% in terms of volume between 2005 and 2013. If in the first five years of 2000, the market was characterized by a constant growth rate of 44%, reaching in 2005 2.2 million of outdoor units sold, in 2013 sales were around 700,000 of the same. The reduction of market value was about -56%, from 2 billion $ in 2005 and 894 million $ in 2013[56]. Nevertheless, it is evident that mini-splits are the dominant technology for residential cooling; they have fulfilled all the main requisites, starting from cheapness. The merit of this technology has been, therefore, to match the

[55] JARN estimations – *JARN, World Air Conditioner Market, May, 25, 2013*
[56] *BSRIA Report, Europe – April 2005 and JARN, May 25, 2013*

affordability to the huge majority of costumers together with installation facility and high comfort level it supplies for indoor air conditioning. Despite the economic crisis, mini-splits are still predominant in the market, with a constant rising in share of inverter (70% in 2013) and reversible (85% in 2005) solutions. The Nordic part of the Country has a higher penetration of such products into the domestic sector, mostly with cooling capacity between 3.5kW and 5kW. According to *European Heat Pump Market and Statistics Report 2013*, only the 9.5% of Italian ATA reversible heat pumps were sold with the main purpose of heating. Specifically, the use of the same is different according to climatic regions:

- NORD: The 50% of ATA reversible heat pumps, with the main purpose of heating, are effectively used also for cooling.
- SUD: The 90% of ATA reversible heat pumps, with the main purpose of heating, are used for cooling.

Multi-splits and mini-VRFs have played an ascendant role; if in 2004 VRF covered the 5% of the total market value of single-multi-VRF split systems, in 2011 VRF systems reached the value of 180 million[57] $ (15% of the total) and 192 million $ (21% of the total) in 2012.

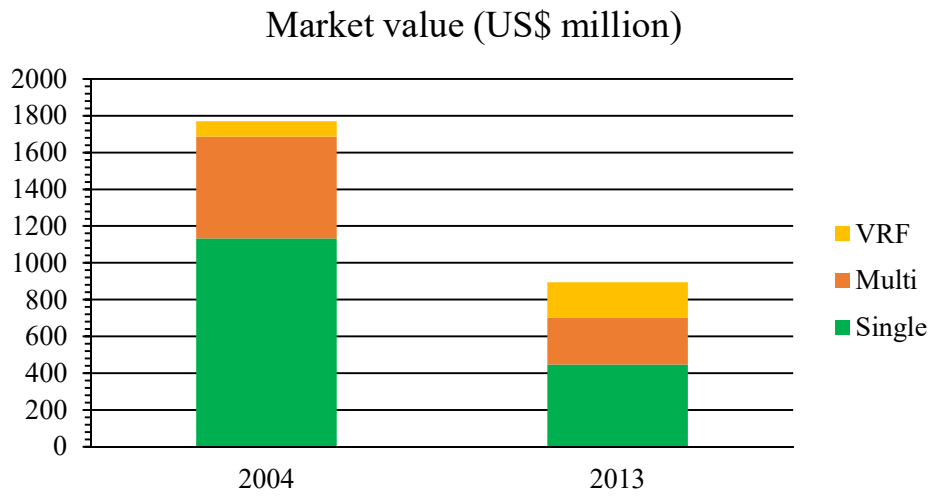


Figure 77 – Italian Splits Market Value (Sources: BSRIA and JARN)

[57] In 2011, mini VRF accounted 5,123 units (total VRF 16,500 units), with a rising share in the residential/light commercial sector, especially in substitution of multi-splits

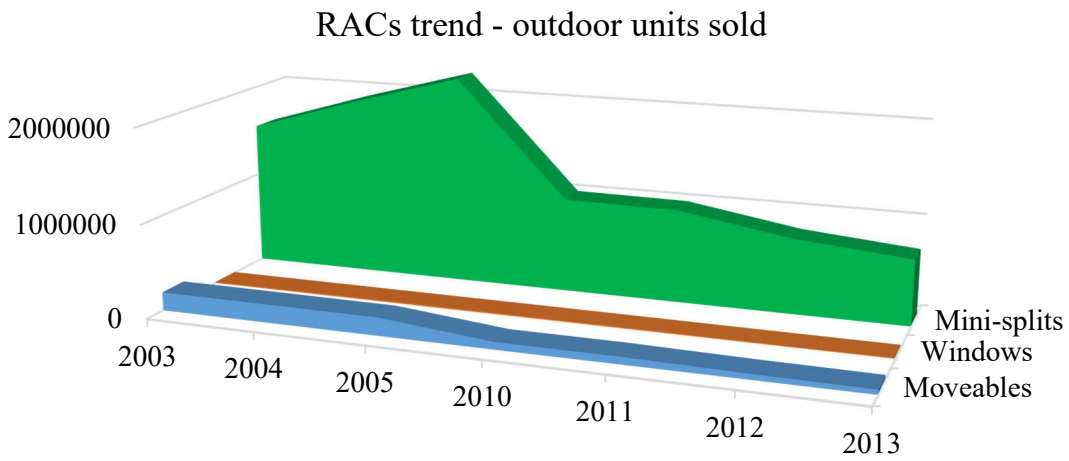


Figure 78 - Italian Market Trend (Source: BSRIA report, Europe, April 2005, and JARN, May 25, 2013)

	splits market (million $)		outdoor units sold		average market price (US $)	
	2004	2013	2004	2013	2004	2013
single	1132,6	447	1523538	543750	743,4012	822,069
multi	553	255	387000	159500	1428,941	2802,508
VRF	84,5	192	5500		15363,64	
total	1770,1	894	1916038	703250	923,8335	1271,241

Figure 79 - Italian Splits Market Evolution (Source: BSRIA and JARN)

As notable from Figure 78 and Figure 79, windows and moveable devices cover a little part of the total market of RACs and their positions are going on reducing because of the strong competition of splits. Windows are mainly in the configuration of "through the wall"; their market consists in replacement of old products and there is no optimistic forecast for them. Moveable solutions are, on the contrary, more favoured than the formers. Despite they cannot compete with mini-splits, the Italian moveable devices' market is the largest in Europe; the reason is related to the fact that moveable devices are the first choice that costumers purchase in order to supply requisites of cheapness, instantaneous resources, and in particular capacity to fulfil sporadic hot spells during the summer season. In addition to that, one should also consider the fact that this kind of product are suitable for households that live in a rented houses. According to Eurostat estimation, the 25% of the Italian population is in a tenant's status; this the reason why families should prefer cheaper solutions, since they are not owner of habitations and, hence, they do not spent much money for this kind of appliances. Nevertheless, the same characteristics that make moveable equipment a preferred technology could become the same that lead mini-splits to take more reputation, going to detriment of the formers.

Water-based systems play a significant role in the Italian scenario, mainly for the commercial sector. FCUs, AHUs[58] and radiant panels are into consideration; as just mentioned, these technologies have been installed manly for offices, supermarkets and other commercial edifices. Nevertheless, a quite important share of residential building stock is equipped with water-based plants, mostly FCUs and radiant panels.

	2000	2001	2002	2003	2004	CAGR
Chillers:						
Recip, screw, scroll	20.564	24.810	28.449	33.465	31.791	11.5%
Centrifugal	123	75	81	40	38	-25.4%
Absorption>350Kw	977	575	660	590	560	-13.0%
Air cooled	19.843	21.486	25.794	28.560	27.126	8.1%
Water cooled	2.693	4.456	3.959	4.945	4.703	15%
<100Kw	17.209	22.956	26.697	30.897	29.351	14.3%
101-400Kw	3.043	1.529	1.402	2.695	2.560	-4.2%
401-800Kw	312	325	350	398	379	5.0%
>800Kw	228	168	178	105	99	-18.8%
Air handling units	19.000	21.000	20.500	20.500	20.000	1.3%
Fan coils	517.776	554.202	665.042	685.000	685.000	7.2%
VAV units	1.446	1.460	1.432	1.200	1.200	-4.6%
Other	-	-	-	-	-	-
Total	559.886	602.122	716.164	695.765	738.000	7.2%

Fonte: BSRIA

Figure 80 - Italian Hydronic Market (Source: Analisi del marcato dei prodotti per il condizionamento dell'aria - Thesis)

Italy is the largest European Country for water-based systems' installation, and this aspect is particularly highlighted by the value of the Italian market in terms of FCUs. French market, which is the second larger in Europe, is ¼ of the Italian one. Fan coil units in Italy are installed in old houses, mainly for heating in multi-family units; the two most common solutions for residential space heating were radiators and FCUs. This product are suitable to produce cooling effects when matched with chillers or heat pumps. Grew of FCUs' sales between 2000 and 2004 was around 32%, reaching 685,000 units with a market value of 22% of the total[59]; in 2011, 400,000 elements were sold, with a market value of US$ 130 million (about 118 million €). It is difficult to estimate the share of such technology in the residential air-cooling market; however, one should affirm that FCUs for air-cooling are quite common in existing multi-family units, since they are yet used as space-heating emitters. On the

[58] FUCs: fan coil units – AHUs: air handling units. The latter are used mostly in hospitals, supermarkets and other big commercial buildings

[59] Total market value of water-based system was estimated to 411 million €; FCUs' share was around € 86 million

contrary, new installation of FCUs find many applications especially into the commercial sector, while for residential buildings other heating systems are generally privileged.

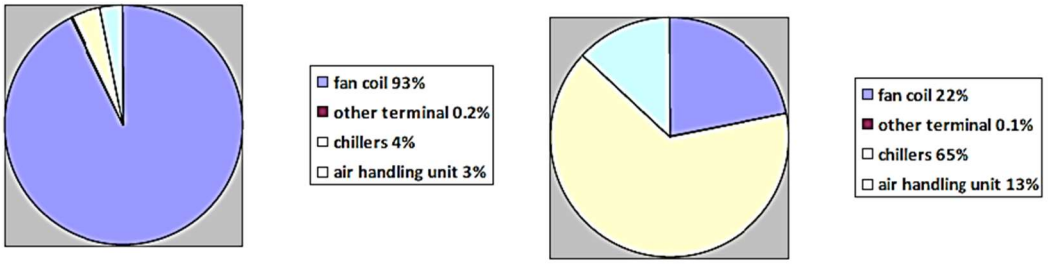


Figure 81 - Italian FCUs - % volume and % value in 2004 (Source: Analisi del marcato dei prodotti per il condizionamento dell'aria)

Chiller market, volume of units								BSRIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011
Air cooled	33619	34932	*36752*	*38678*	*40716*	*42872*		40000	43000
Water cooled	2314	2784	*2850*	*2919*	*2989*	*3063*		5050	5200
<100 kW	32269	33882	*35577*	*37355*	*39223*	*41184*			
>100 kW	3664	3834	*4025*	*4242*	*4482*	*4751*			
Grand Total	35933	37716	*39602*	*41597*	*43705*	*45935*		45050	48200

Table 14 - Italian Chiller Market – (Source: BSRIA and JARN)

Heat Pumps Type	**2010**	**2011**	**2012**	**2010/2012 evolution**
ATW	12601	12830	12801	1,59%
WTW	1082	1327	1311	21,16%
GSHP	178	409	408	129,21%
ATA	109471	113173	104685	-4,37%
Total	123332	127739	119205	-3,35%

Table 15 - Italian Heat Pump Market (Source: EHPA)

As concern chillers, the 50% of products sold through the years was characterized by cooling capacity under 20kW and no decline has been recovered up to now. This result underlines the importance of the residential and light commercial sector in the field. On the other side, ATW, WTW and GSHP configurations have recorded good results in the last few years, especially between the two-year period 2010-2011. This result confirms an ascendant propensity for the use of heat pumps, especially in combination with hydronic heating and cooling plants.

Although radiant cooling alternative is not comparable in terms of market and number of installations to other air-cooling systems, some considerations regarding the huge growth of the UFH systems in Italy are important. The grew of installation of radiant heating and cooling panels was around 13%, moving from 11 million m^2 in 2013 to 12.5 million m^2 in

2015[60]. As one should notice in Figure 82, a different trend was recovered between new and existing residential edifices. While the installation of radiant panels in the former have been quite constant, an ascendant tendency in the renovation sector is evident. In particular, nowadays the 50% of the single-family houses is equipped with UFH systems, while as concern multi-family units the share is quite lower. This aspect should be explained considering that the plant design in multi-family houses is decided by contractor and not by flats' buyers; it means that the builder has a different point of view toward economic and qualitative features of the dwelling, privileging so money-saving solutions. Therefore, the percentage of households that should install radiant panels, both for heating and cooling, is higher in the single-family category than in multi-family one. Same conclusions emerge in case of installation of reversible hat pumps. FCUs and radiators still cover relevant positions for space-heating in multi-family units.

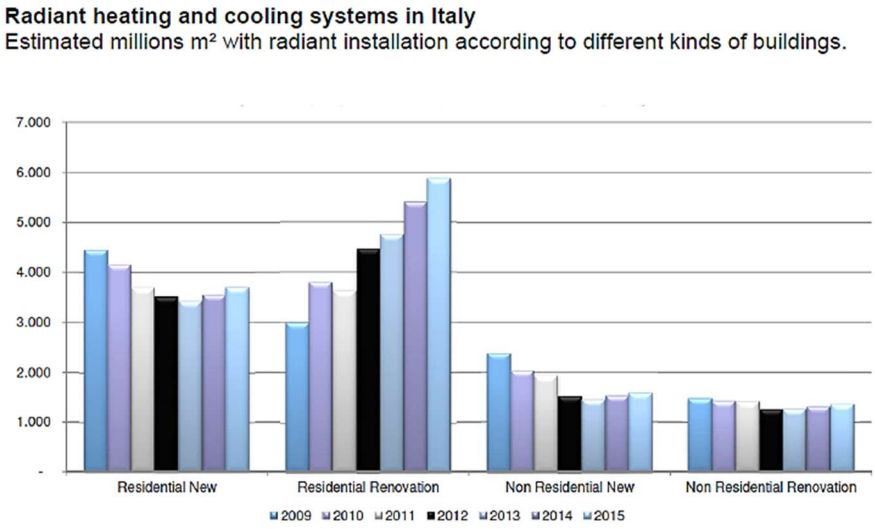


Figure 82 - Italian Radiant Market (Source: Q-RAD)

The share of radiant panels UFH for new domestic building reaches the 42% in 2015, starting from the 26% in 2009[61]. Although the installations are constant since some years, the share is increasing as demonstration of the reputation that these products cover for new residential constructions. Radiant heating and cooling systems are spreading quickly also in renovated residential buildings (+17% from 2009)[62]. In particular, the installation of radiant products in existing buildings is more common for single-family units that the multi-family ones. The reasons are related to larger financial budgets, as well as more care toward operative

[60] *Radiant Market in Italy, Q-RAD*
[61] Idem
[62] Idem

consumptions. Taking into account both single and multi-family dwellings, the share of radiant systems is 21% of the total renovated floor area.

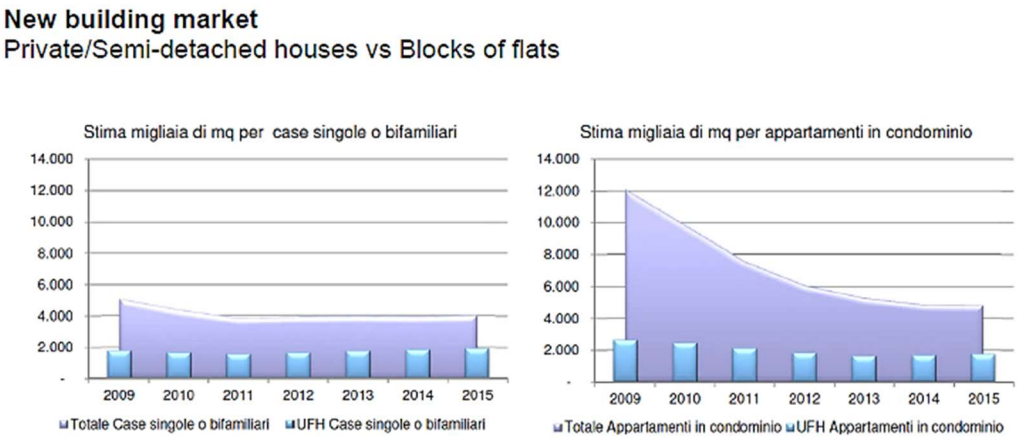


Figure 83 - Italian Radiant Market in New Buildings (Source: Q-RAD)

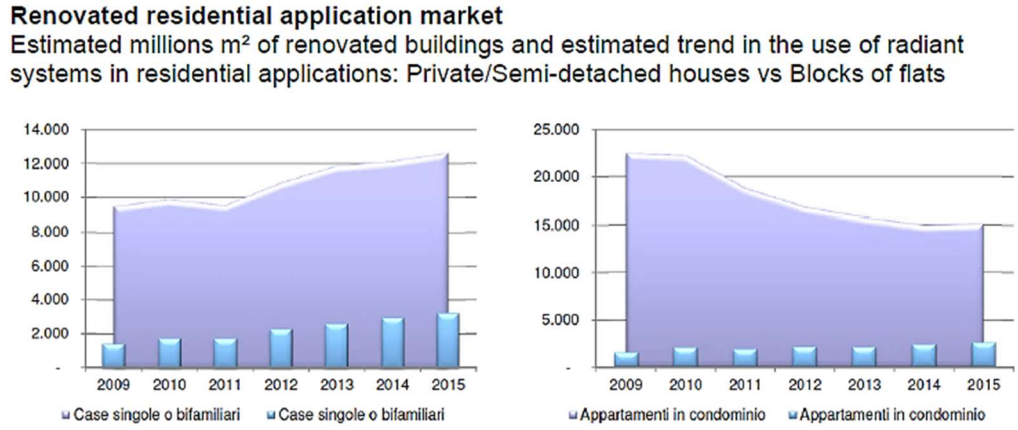


Figure 84 - Italian Radiant Market in Existing Buildings (Source: Q-RAD)

CONSIDERATIONS

It is important to underline that the huge increasing and spreading of cooling devices in the residential sector has been strongly driven by a deep sense of necessity more than by wealthy reasons. This necessity is something diffuse in the majority of population and do not involved only people in better economic conditions. This aspect reflects a cooling demand based on technologies that fulfil specific requisites. Indeed, it is clear that a solution, which has been able to fit together cheapness and good comfort quality, has been the most successful one. Mini-splits has dominated installations and their share in the total penetration of cooling application in the domestic sector is over 90%. A part from economic and comfort reasons,

other merits of the technology into consideration are relative to installation procedure; it is an adaptable system for each type of house, simple in installation and use, as well as not so invasive in the indoor environment. Furthermore, one should not forget the importance that availability and awareness of this resource has had for its achievement in the Italian and European market. While other alternatives as moveable devises and through-the-wall systems did not play a relevant role and they are going not to change their positions, applications as radiant panels and FCUs should cover more reputations in the future. Radiant cooling, nowadays, covers a domestic penetration of 4-6%. The attention toward combined solutions supported by renewables sources might have several influences on the same. There will be a more massive use of solar thermal panels, PVs and heat pumps in the residential sector; hence, cooling applications should progress toward better interactions with the mentioned elements.

Nevertheless, we have to remember that the main driver force would not be the new residential construction industry (CAGR 0.5%), but the segment of renovation and refurbishment. However, one has to consider the current economic national status too, which seems to recover slowly. The Italian existing stock is hugely dominated by multi-family edifices, erected before 1990s. Therefore, households are going to prefer solutions that are suitable with their flats, not invasive, cheap and with high installation facility. This is the reason why, in existing multi-family segment, split devices, with an increasing share of multi-type configuration, together with FCUs are supposed to be dominant in the future cooling market. While the formers are adaptable for any kind of application and they benefit of a great reputation by the population, the latter represent a good alternative, on one hand as substitution of old thermal emitters (radiators), and on the other hand as reversible system for both heating and cooling. On the contrary, in the next decade, the role of radiant panels is going to improve mainly in new constructions, also for multi-unit edifices.

SPANISH CASE

Spain is the second most important European cooling market due to warm climatic conditions, especially in Continental and Mediterranean zones. The penetration of air conditioners is relevant, for both the commercial and residential sector. According to JARN data, the penetration is around 72% and 44% respectively; "by 2016, this is forecast to rise to 75% and 47%"[63]. It is clear that, as the Italian case, the necessity sense to face up to hot temperatures has driven a strong demand during the past decades. Wealthy and luxury are not recognizable as main driven criteria in the Spanish scenario. Another result emerged from the previous data deals with the high penetration in the residential sector, which can lead to a sudden stagnation of the existing stock's market. This is the reason why the attention is more projected to new buildings; nevertheless, the Spanish construction industry has recorded worst[64] consequences in the past decade due to economic crisis. Since 2008, indeed, demand for residential property declined because of the weak economy, high unemployment, shrinking disposable incomes. According to *CIC*, the construction industry, and so the domestic segment, should recover in the next few years with a CAGR of 3.16%, reaching US$ 97.3 billion in 2018[65]. In particular, multi-unit buildings industry's fall was about -16% between 2008 and 2013, but better expectations are estimated for the same with a prognosis of +4%. However, some attentions are dedicated to the buildings' stock, mainly focusing on the typology of dwellings, structural characterization, as well as climatic classification. In particular, *Census 2011* provides number of edifices and houses:

- Number of edifices: 9,804,090
- Number of dwellings: 25,208,623
- Average dwelling size[66] = 103m^2

A relevant share of residential edifices was built in the period 1971-2001, when the number of new buildings were over the threshold of 1.2 million per decade. In addition, the decade 2000-2010 covers the hugest position, since 4 million[67] of new dwellings were built. Therefore, the past decade plays a strong role in the current stock; for instance, in 2008,

[63] *JARN, May 25, 2013*
[64] *Residential Construction in Spain, Dashboard* Report – Source: CIC, construction intelligent center
[65] Idem
[66] according to ENTRANZE project "multi-family dwellings are on average 22% smaller than the single-family dwellings, with an average size of 86m^2, compared to the 111m^2 for single-family dwellings"
[67] ENTRANZE, The challenges, dynamic and activities in the building sector and its energy demand in Spain

habitations built after 2000 represented the 20% of the total. Nevertheless, since 2007 a deep restriction of the construction industry has been recorded. However, as ENTRANZE confirms, the 58% of the stock in 2008 was erected after the first thermal regulation (1980).

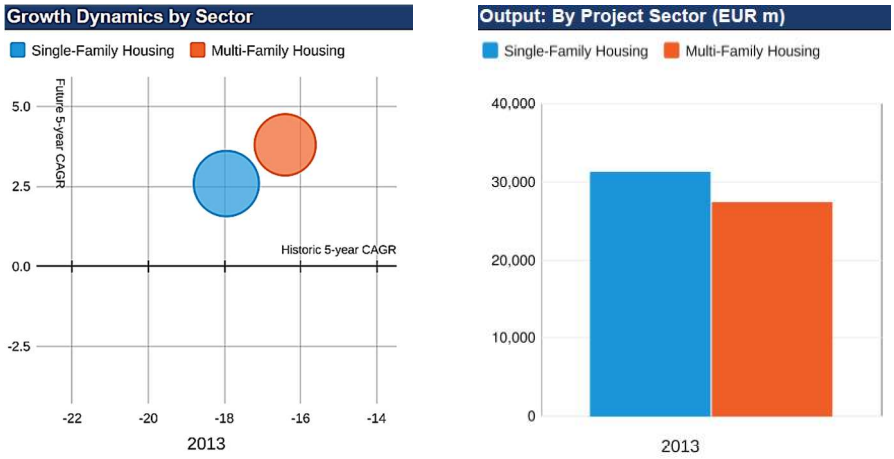


Figure 85 - Spanish Construction Industry (Source: CIC, Construction in Spain – key trend and opportunities to 2019)

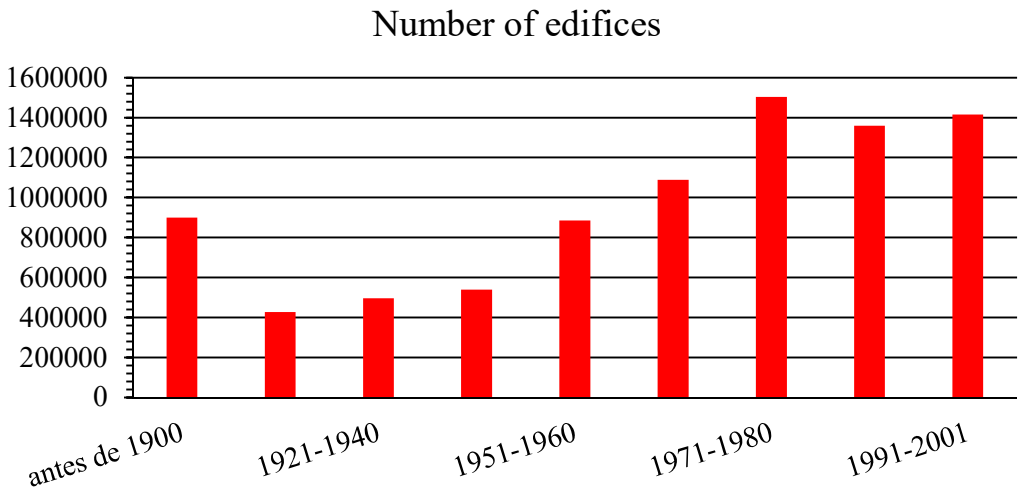


Figure 86 - Spanish Construction Periods (Source: Catálogo de tipología edificatoria residencial)

Figure 87 shows that the 70% of the Spanish building stock refers to multi-unit typology. Moreover, the majority of the population is concentrated in the Mediterranean zone; it is significant that 53% of the total dwellings are located in the Mediterranean area, and the share becomes bigger (86%) if one considers also the continental one. This result highlights the connection between high population and warm regions as a driver factor that should stimulate a huge domestic cooling demand. In order to describe these climatic areas, some representative cities have been selected:

Figure 87 - Spanish Climatic Zones (Source: Catálogo de tipología edificatoria residencial)

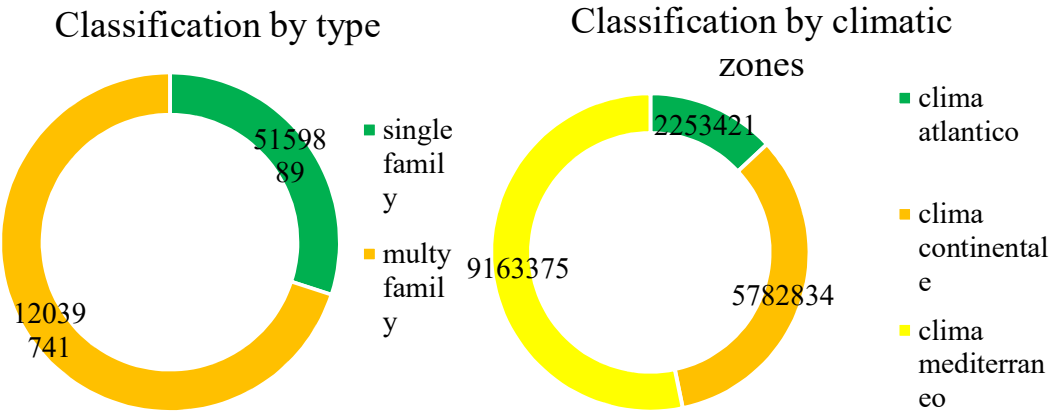


Figure 88 - Classification of Spanish Buildings Stock (Source: Catálogo de tipología edificatoria residencial)

- *Bilbao*: the climate of Bilbao is oceanic-humid, with mild temperatures during the whole year. Summer seasons are warm, with maximum temperatures in August around 26°C.
- *Madrid*: the climate of Madrid is Continental, characterized by quite cold winters and very hot summers, with average temperatures around 25°C in July and August and maximum values over 35°C. However, there is low humidity and this aspect makes the Madrid climate similar to desert one.
- *Barcelona-Malaga*: the Catalano climate is characterized by warm and summers, with average temperatures under 28°C, but with a strong *xafogor*,

that is to say with a heavy humidity level. The same is in *Malaga*, which is described by medium humidity value of 66% and maximum temperatures in August over 30°C.

Climatic peculiarities, together with reasons related to cheapness and products' availability, have led RACs to obtain a predominant position on the residential air-conditioning field. As happened in Italy, in the first years of 2000s the market experienced a huge increment of the cooling demand, reaching in 2005 a total value of around US$ 2 billion. Mini-split configuration played the most relevant role, mostly because of the ability to unify low prices and good comfort effects. Mini-splits are a ride product since many years, and their availability, as well as their huge awareness in Europe, had contributed to make them more affordable and competitive, assuming a privilege position in the market. Mini-splits cover the 98% of the sold RACs in 2004, with a market value of US$ 1.9 billion. As concerns the setting, a deep prevalence toward inverter configuration is recorded, as well as for heat pumps, whose share is over the 80%[68] of the total since 2004. Nevertheless, the drastic economic crisis have had a deep impact on the market, throttling the sales of all kinds of products. As one should recognize from the following data, the recorded RACs' reduction has been enormous, about -70%[69] in terms value; for instance, splits' sales fold "from nearly US$ 880 million in 2011 to just over US$ 600 million and for the current year are expected to end up at around US$ 570 million[70]". Differently from the Italian case in which VRF application has shown an increasing share in the market value, in Spain the crisis has influenced all kinds of application, indiscriminately. The price is the reason why there is a tendency to drop out of multi-split configuration, since Spaniards "find it cheaper to buy several single units instead"[71].

Residential/Light commercial market, volume of outdoor units										BSRIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	20300	19184	*18128*	*17131*	*16189*	*15380*		32000	26000	20000	19400
Windows	11500	10000	*8500*	*7000*	*6000*	*5100*		2200	1700	1400	1300
Ductless-Splits	1102963	1389481	*1495082*	*1579507*	*1626892*	*1671448*		872000	722000	573000	539000
Grand Total	1134763	1418665	*1521710*	*1603638*	*1649081*	*1691928*		906200	749700	594400	559700

Table 16 - Spanish Residential/light commercial Market (Source: BSRIA and JARN)

[68] *BSRIA, Europe Report, April 2005*
[69] *BSRIA, Europe Report, April 2005 and JARN journal, May 25, 2013*
[70] US$ 570 million cover single splits, VRF configuration and ducted splits. In particular, the share in terms of value is respectively 70%, 10% and 20%. In Figure X, on the contrary, single, multi and VRF splits are reported. For multi-splits the share is estimated in 2013 to be 10%, as was in 2012.
[71] *JARN, May 25, 2013*

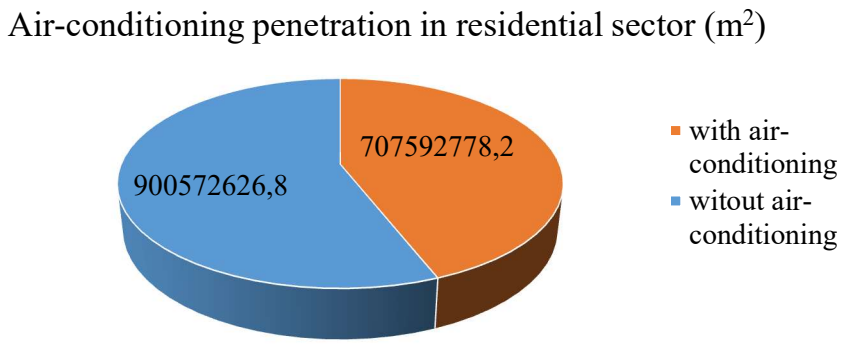


Figure 89 - Spanish Air Conditioning Penetration (Source: JARN, May 25, 2013)

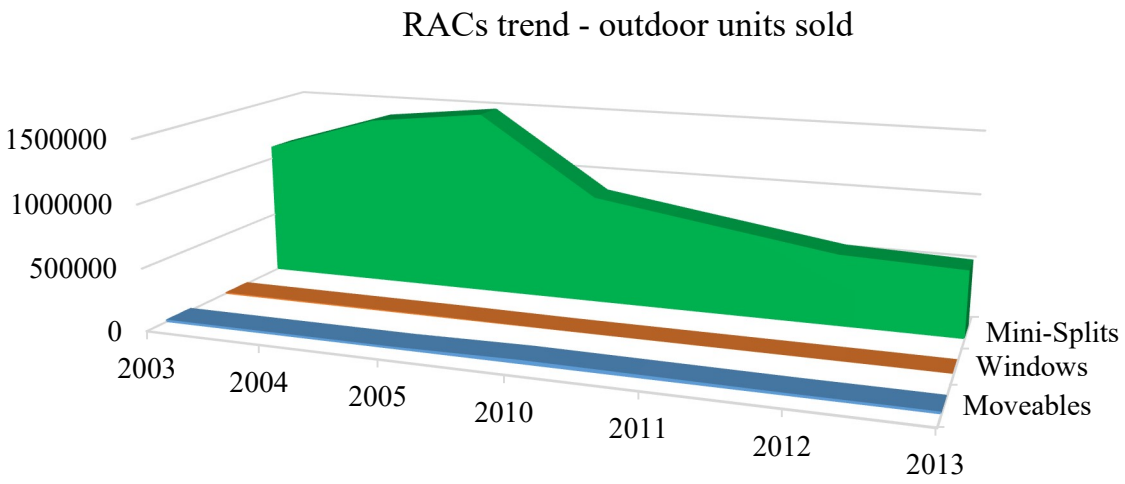


Figure 90 - Spanish RACs Trend (Source: BSRIA and JARN)

	splits market (million $)		outdoor units sold		average market price	
	2004	2013	2004	2013	2004	2013
single	1474,6	399	1133365		1301	
multi	268,8	45,6	248787		1081	
VRF	116,6	57	7329		15911	
total	1860	501,6	1389481		1338,629	

Table 17 - Spanish Splits Market Evolution (Source: BSRIA and JARN)

Windows and moveable devices cover a little part of the total market of RACs and their place is going on reducing because of the strong competition of splits. Windows are going to exit from the market and up to now their sales are basically related to refurbishment and replacement. Nevertheless, as just mentioned, many manufactures are going to put windows out from their portfolio. Moveable products, on the contrary, should keep their market position. As recognizable from the previous pictures, moveable equipment's sales grew during the crisis period, and now they are experiencing a negative tendency toward lesser

applications. Their main market is focused on the Atlantic area[72], since they represent the best solution to fulfil sporadic and not high cooling demand during summers. In addition to that, they also satisfy cheapness requirements, which are relevant in Spain. It is important to highlight that the 90% of moveable products sold are for the residential sector, as demonstration of their adaptability to domestic needs. In conclusion, moveable solution might recovered if in the Nordic part of the Country there will be some strange heat waves.

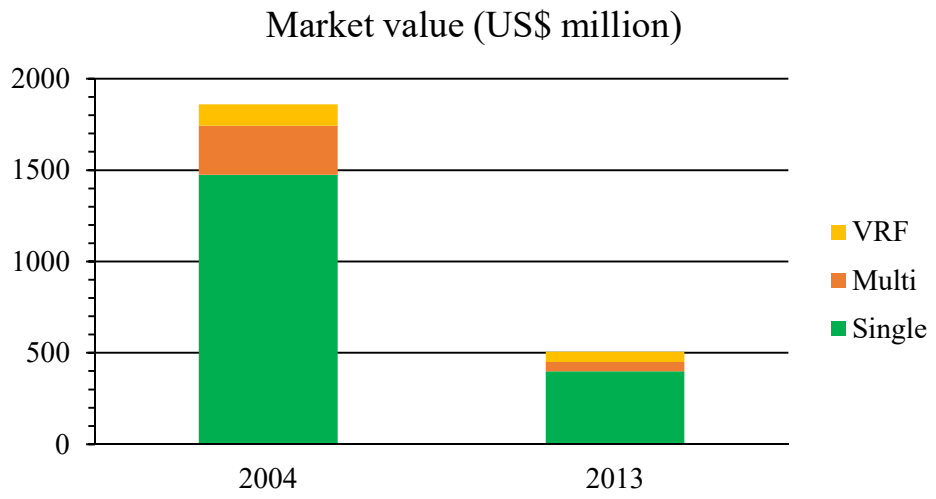


Figure 91 - Spanish Split Market Value (Source: BSRIA and JARN)

% de equipos	Clima atlántico	Clima continental	Clima mediterráneo	Parque de edificios
Portátil	67%	9%	5%	6%
Aire acondicionado	5%	25%	12%	16%
Bomba de calor	28%	66%	83%	78%
Total	100%	100%	100%	100%

Table 18 - Climatic Classification of Equipment (Source: Catálogo de tipología edificatoria residencial)

Some social aspects and the different typologies of cooling demands inside Spain has characterized some special trends. Specifically, as one should recognize from Table 19, splits, moveable elements and window configurations have had different destinations. Portable devices, for example, due to the mild-humid climate and not so rigid in summer, are strongly inserted in the Nordic Spanish regions. On the contrary, the penetration of heat pump configuration is over 50% in both Continental and Mediterranean zones, because of mild

[72] The share of moveable devices in dwellings in the Atlantic area is around 67%.

winters and hot summers. As concerns only cooling setting, the highest diffusion is in the Continental area, where the climate is characterized by cold winter and hot dry summers. This aspect has influenced the choice toward only cooling products, as systems separated by the heating ones. Table 20 shows that the penetration of air-cooling systems is higher in multi-unit than in single-family edifices[73]. First, it is evident that heat pump setting is more common in single-family habitations; this conclusion is due to the fact that households living in single-unit buildings have more capital. On the contrary, only cooling configurations, cheaper than heat pump ones, are spreader in flats, as result of the apartment residents' propensity toward economical solutions. In addition to these reflections, the breakdown of ownership has to be taken into consideration, in order to underline the connection between the same and predisposition toward systems more or less low-priced. The share of owner occupied dwellings is predominant in both multi-family and single-family edifices, but the share of private renters in multi-type category is over the threshold of 30%.

Nº de hogares		<1900	1900-1920	1921-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2001
Vivienda unifamiliar	Dispone de sistema de refrigeración	3%	4%	5%	7%	8%	10%	12%	18%	18%
	No dispone de sistema de refrigeración	97%	96%	95%	93%	92%	90%	88%	82%	82%
Vivienda plurifamiliar	Dispone de sistema de refrigeración	11%	13%	15%	14%	15%	16%	18%	20%	21%
	No dispone de sistema de refrigeración	89%	87%	85%	86%	85%	84%	82%	80%	79%
Parque de edificios	Dispone de sistema de refrigeración	7%	9%	11%	11%	13%	15%	17%	19%	20%
	No dispone de sistema de refrigeración	93%	91%	89%	89%	87%	85%	83%	81%	80%

Fuente: Instituto Nacional de Estadística Censo 2001

% de equipos	Vivienda unifamiliar	Vivienda plurifamiliar	Parque de edificios
Portátil	4%	7%	6%
Aire acondicionado	12%	17%	16%
Bomba de calor	84%	76%	78%
Total	100%	100%	100%

Fuente: IDAE 2012

Table 19 - Spanish AC Penetration in Current Stock (Source: Catálogo de tipología edificatoria residencial)

[73] According to *Catálogo de tipología edificatoria residencial*, the percentage value of hogares equipped with air-cooling systems through the year was higher for multi-family building instead of single-unit ones.

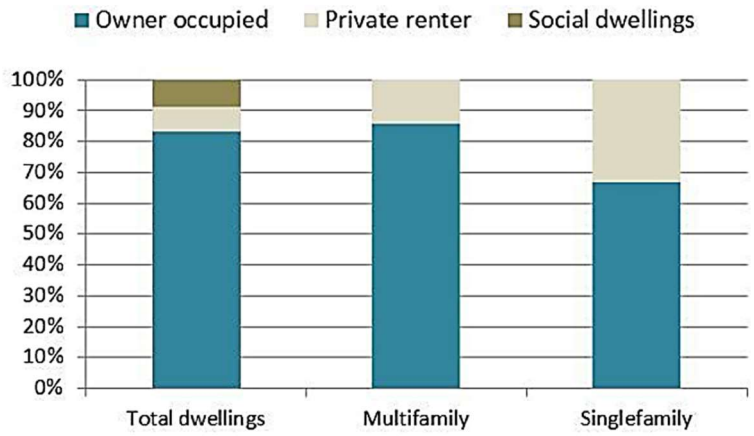
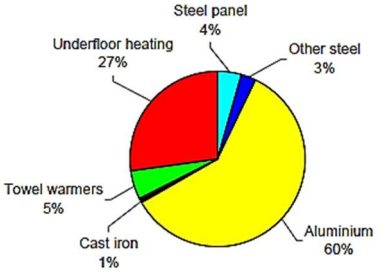


Figure 92 – Spanish Social Breakdown (Source: ENTRANZE project, Spain)

The contribution of hydronic systems in the residential cooling contest is limited to low percentage share. From interviewing some UPONOR experts, it emerged that the position covered by air conditioners, and in particular by splits, is untarnished. Fan coil units and radiant cooling are two secondary technologies in the Country, narrowed to just few applications. The amount of FCUs' sales in Italy, although the crisis, have been of some hundreds of thousands since past decades, while the Spanish one is just around some tens of thousands. For instance, Italian FCU sales were 400,000 units in 2011 and in the same yeas in Spain were sold 63,000 FCU units[74]; in terms of value, the difference becomes more evident, with an offset of around US$ 100 million. As concerning the radiant cooling technology, it is quite unknown in the Country, with an amount of few installations[75]. Beside this, as emerges from BSRIA study *Radiator and underfloor heating Spain, World Heating 2009*, underfloor heating is gaining market share, with a special view on the new residential sector. On the contrary, the penetration of radiant panels has been not so relevant in refurbishment of existing edifices, mainly due to costs and installation complexity.

Although underfloor heating (and with it probably also the cooling configuration) is expected to going on in its ascendant trend toward a more important position on the heating market, going to detriment of radiators, we have to consider some limits. The strong dependence to new construction industry is securely the main factor that would influence the tendency of radiant installations in dwellings, mainly for heating and, hence, for cooling too. Optimistic prospective are far from the reality since the feeling is toward a slowed-down recovery, due to economic reasons and overstock problem.

[74] *JARN, November 25, 2012*
[75] Radiant cooling covers the 2-4% of the global residential cooling market



Source: BSRIA

Underfloor market forecast, volume (million metres), 2009-2013

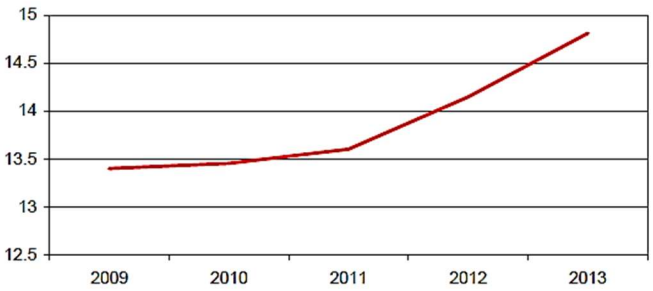


Figure 93 - UFH Penetration (Source: BSRIA - Radiator and underfloor heating Spain, World Heating 2009)

CONSIDERATIONS

Spain has covered a fundamental position in the growing European cooling demand in the past decade. The reasons of such huge increase are related to the fact that Spain, thanks to its climatic features, has been an important cooling-potential market. The contemporaneity of high demand with a simple and affordable technology, such as the split one, has led an uncontested progress, mostly in the residential sector. The split solution has been able to fulfil several and different requisites of citizens. Installation facility, together with the enormous adaptability/flexibility to be applied to every kind of domestic construction (single and multi-units, new and existing), in each regional climate (from the arid one, typical of Madrid area to the most humid typical of Barcelona and Malaga regions), have led mini-splits to be the only one protagonist of the Spanish domestic cooling market. As previously mentioned, one should not forget also the importance of the economical aspect; indeed, Spaniards take care of money saving and this is reflected to a particular inclination toward low-cost habitations and cheap appliances. It is emblematic the predisposition of new construction industry to build multi-family and high-rise buildings with low quality materials, equipped with systems that have to ensure only cheapness. This is the reasons why, on one side radiators are privilege for heating,

and on the other side, no cooling solutions are considered into the dwelling' project. In the majority of cases households purchase split products in order to install the same in their existing habitation.

Construction industry would be probably the key driving force for a new increase of the residential cooling demand. Nevertheless, some problems are identifiable in the same background. On one hand, new constructions are deeply influenced by both economic instability and overstock; it is not sure that a plausible financial recovery of Spain would increase new manufactures, due to the persistent excess of existing buildings. On the other hand, same reflections should be made for requalification of old edifices; a relevant part of the residential stock is represented by structures build after 2000, and it means that also refurbishment's field is quite paralyzed. Stagnant condition of construction industry should have a strong impact also in the heating and cooling market, and this influence is emphasized when one considers solutions that are privileged in new habitations, as radiant technology.

Besides doubtful prognosis, energy saving and efficiency requirements are supporting an ascendant tendency toward solutions that guarantee better house's energy performance. This more awareness for efficiency and environmental issue finds confirmations in a growing demand of equipment like condensing boilers and solar power systems for heating and DHW; also heat pump configuration is going to cover a more relevant reputation, especially in the southern regions of Spain. Installations of ATA, ATW and GSHP[76] "are starting to become quite popular in the Levante and East cost areas, motivated by the weather conditions experienced in these zones"[77]. Many should be the repercussion of this reflection; an ascendant penetration of reversible systems in South of Spain is expected. It is plausible that splits might have a big potential in the coast regions, for both winter and summer seasons, taking into account that heating and cooling demand are quite similar during the year. As concern Continental area, the market has to face up with rigid winters and severe arid summers; in this case, only cooling plants or combined ones with high H&C capacity are required.

[76] ATA = air to air heat pump; ATW = air to water heat pump; GHP = geothermal heat pump
[77] *BSRIA - Radiator and underfloor heating Spain, World Heating 2009*

GERMAN CASE

Germany represents one of the main key European Countries because of residential energy consumptions and industry construction. In general, Germany has to be considered with high attention since it is the Europe's largest and the world's fourth largest[78] economy. If German economy has experienced a period of stagnation until 2005, described by negative growth rates in the construction sector and high unemployment, nowadays the reality is completely on the other way round. GDP per capita was around 35,000€ in 2014 and, after the Nordic richest Countries, is the highest one in the continent. Germany has changed its position on the European panorama as concerns unemployment. In 2005 the Country was characterized by the highest values compared to the other key five Members' ones; in 2014 Germany, together with UK, enjoys a prominent position, with a rate of 4.7% in April 2015, under the European average value. This is a representative factor of the German population status.

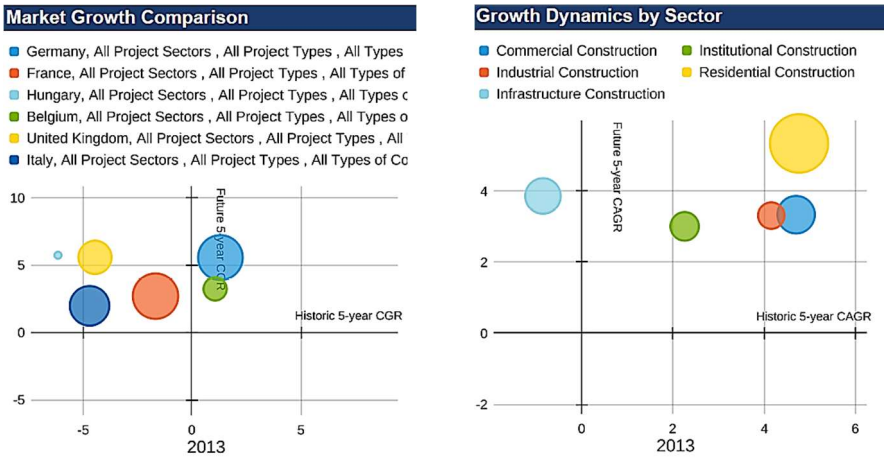


Figure 94 - German Construction Industry (Source: Construction Intelligence Centre CIC)

Between the first years of 2000s and nowadays, Germany had to face up with the international financial crisis too. "By spring 2009 the German economy has found itself in the middle of the deepest recession since the foundation of the Federal Republic"[79]. However, the impact of the downturn has been less detrimental than in other European Countries, as Spain, Italy and in particular Greece. As confirmation of that, in spite of Italy and Spain, the German construction industry has recorded a positive CAGR of 4.22% during the five-years period 2009-2013 and from the data below it is clear that the most optimistic expectation are reserved for the German case. According to *Construction Intelligence Centre (CIC)* the German

[78] *Radiators and underfloor heating, Germany, World Heating 2009*
[79] *Radiators and underfloor heating, Germany, World Heating 2009*

construction industry is supposed to move from a value of EUR 260.0 billion in 2013 to EUR 321.1 billion by 2018, with a growth rate of 4.31%. A part from that, what it is fundamental within the scope of the present analysis is the particular role that the residential sector should play in the few next years. Data available for *CIC* are significant for understanding the depth of the domestic segment: "with a value of EUR 116.8 billion and an industry share of 44.9%, residential construction was the largest market in 2013, representative of a review-period CAGR of 6.24%"[80]. Furthermore, the development of the domestic segment is supposed to be the fastest increasing one with a probable CAGR of 5.35%, to value EUR 151.5 billion in 2018. Rising income and favourable employments conditions are two index of the stable and healthy contest in which residential market has had the possibility to expand itself. At the same time, the economic importance of Germany in the EU, as well as its industry stability and population rising wealth's conditions, are expected to be two of the main motors for a positive path for the residential industry. In addition to that, also the reduction of housing interest rates and the trend towards urbanization are likely to support the increasing demand of private housing.

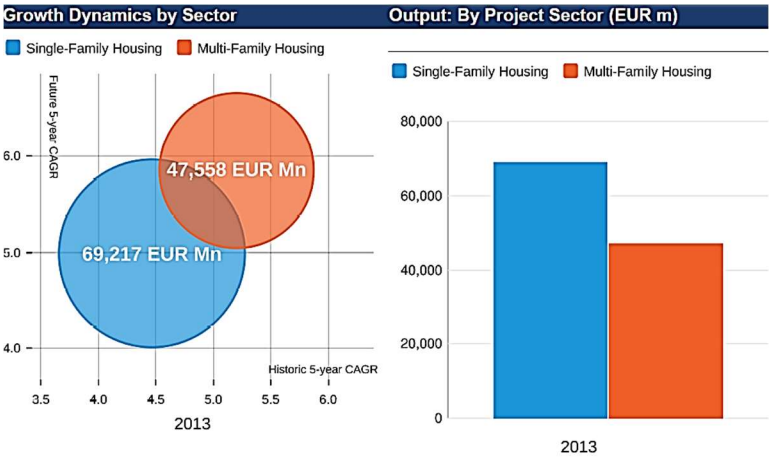


Figure 95 - German Construction Industry Outputs (Source: Construction Intelligence Centre)

Nevertheless, in order to be more detailed, some analysis in the difference between the single-unit and multi-units building field should be useful. In particular, the segmentation regarding single family-houses has been the largest one in the residential market, with a share of 53.9% and a value around EUR 70 billion in 2013. Furthermore, according to *CIC*, the same category is expected to be the most prominent in the forecast-period 2013-2018, since it has been predicted a CAGR value of 4.99%, that is to say a market output of EUR 88.3 billion. On the contrary, although the multi-unit hosing segment is less relevant in terms of market

[80] *Construction in Germany – Key Trends and Opportunities to 2018*

value, the same have covered a significant position since it is the category with highest CAGR in both five period 2008-2013 and 2013-2018.

It is also relevant to analyse the building stock, with a special view on "old" buildings. The target is to make a clear overview on the housing typologies and their construction periods; all these aspects should have some influences in many backgrounds, in particular for refurbishments and requalification. Figure 96 and Table 21 show that old existing buildings cover a predominant share in the existing stock. In particular, the twenty-year period between 1958 and 1978 has been the most proliferating one since over 5 million of residential edifices were built. This aspect is very meaningful since the majority of the current buildings' stock was erected before the first thermal regulation. It is clear that the study of periods' construction is a significant indicator of the quality and standards of construction, especially from an energetic point of view. Nevertheless, German citizens have conducted many actions toward old buildings' requalification[81]. According to *TABULA project,* nearly the half of the roof area of the old existing habitations has already been thermally upgraded. Considerable results are recorded also for the windows refurbishment to low e-glazing solutions, which has the highest annual insulation rate; on the contrary, the progress of wall and especially of floor/cellar ceiling is smaller. Further information regarding the percentage of thermally refurbished envelop areas are described in Table 22. In particular, from the data emerges that a relevant level of requalification has been reached also for single and multi-family edifices erected in the period 1979-1994, concerning roofs and windows renovations. Specifically, in both types of buildings the percentage of roofs refurbished is around the 24%.

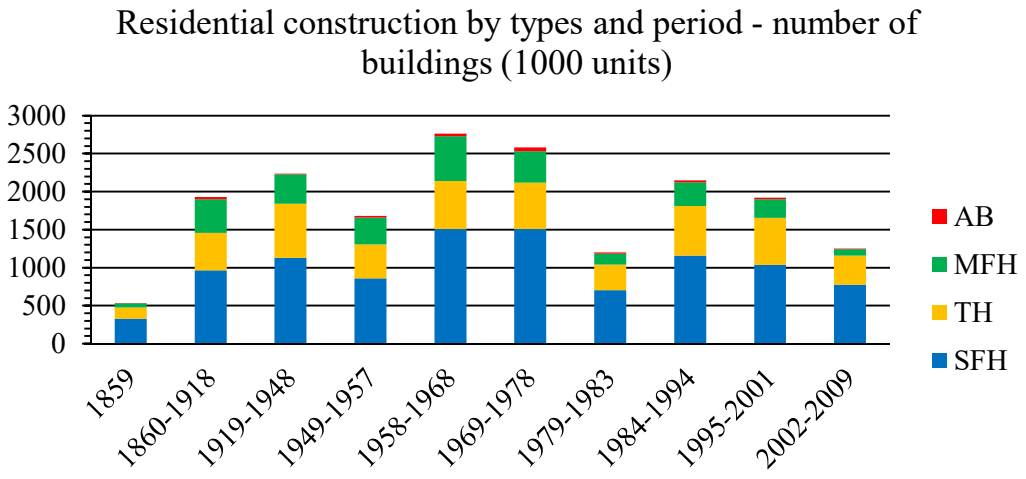


Figure 96 - German Construction Periods (Source: TABULA-Scientific Report Germany-)

[81] According to *Tabula, scientific report Germany*, old buildings are the ones erected up to 1978

DWELLINGS (*1000)	SFH	TH	MFH	AB	SUM	%
1859	399,9	181	214	11,1	806	**2,054602**
1860-1918	1210,2	617	2177	528,8	4533	**11,55523**
1919-1948	1388	840	1911	126	4265	**10,87206**
1949-1957	1058,5	546	2003	307,5	3915	**9,979862**
1958-1968	1948,3	749	3348	817,7	6863	**17,49471**
1969-1978	1914,7	685	2313	1366,3	6279	**16,00602**
1979-1983	881,3	374	852	355,7	2463	**6,278518**
1984-1994	1396,7	722	1826	605,3	4550	**11,59856**
1995-2001	1203,3	674	1390	407,7	3675	**9,36807**
2002-2009	858,6	409	461	151,4	1880	**4,792373**
SUM	12259,5	5797	16495	4677,5	**39229**	

Table 20 - German Construction Period (Source: TABULA project)

Percentage of modernised element area (with improved thermal protection) percentages related to building numbers of the respective classes SFH I - MFH II				
Building classes	**SFH I**	**SFH II**	**MFH I**	**MFH II**
	until 1978	**1979-1994**	**until 1978**	**1979-1994**
walls	20%	7%	26%	15%
roofs / upper floor ceilings	47%	24%	48%	23%
basement / cellar ceiling	10%	3%	11%	7%
windows*	35%	12%	44%	24%
modernisation of buildings erected after 1995 (SFH III and MFH III) neglected				
*percentage of thermal protection glazing (window installation after 1995)				

Table 21 - Percentage of modernised element area (Source: TABULA-Scientific Report Germany-)

Thanks to *TABULA project* some representative estimations about building stock are available:

- Number of buildings: 20,500,000
- Number of dwellings: 41,000,000
- Average size[82]
  - Single-unit: 110 m^2
  - Multi-unit: 58m^2

The largest fraction (53%) of the housing stock is related to single-family houses; the position covered becomes more significant if one considers also the terraced house, for a total portion of 83%[83]. The 73% of the same are in the configuration of only one apartment, while the rest are duplex habitation or single-family house with an additional apartment. The fraction of multi-family houses, and in general of apartments' blocks, is around the 17% of the total residential building stock. The portion covered by the same, on the contrary, become larger if the analysed parameter is the number of dwellings. The number of habitations inside multi-

[82] *ENTRANZE project*
[83] *TABULA, Scientific Report Germany*

unit edifices are over 21 million[84] and represent more or less the 54% of the total dwellings stock.

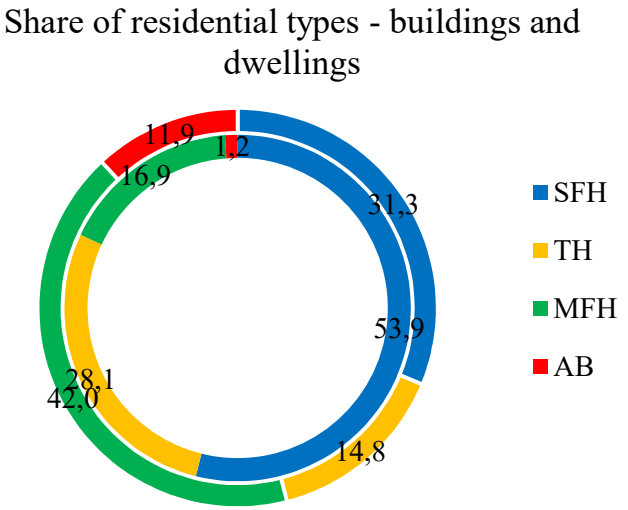


Figure 97 - German Share Residential Types (Source: TABULA-Scientific Report Germany-)

Germany is one of the smallest European Market for air conditioning and this becomes more evident if residential segment is considered. According to JARN journal, the penetration in houses is just around the 3% in 2013[85], while in the commercial sector the same reaches 55%. Germany is located in a position exposed to mild and humid airflow coming from Atlantic zones, cold air from the Nord and gelid streams from Russian regions. As result of this combination, German weather is continental, with cold winters and quite warm summers; at the same time, it is unstable, with sudden changes in temperature and humidity. Hence, beside the average temperatures are not so rigid, German central-south and west regions should experience some gelid winter days, as well as torrid seasons. It is clear that the lack of large and hot summers does not make the air-conditioning market so fruitful, especially for residential applications. Nevertheless, some external factors are currently leading the same to progress. One motor should be identified in the rising of comfort requirements. In particular, since people are used to feel comfortable while frequenting public, commercial and working places, most of the time air-cooled, they should prefer same conditions in their own houses.

Because of the climatic characterization of brief torrid periods during the year, the air conditioning market has developed mostly toward RACs, specifically moveable devices and

[84] Idem
[85] According to JARN, 2013 the air conditioning penetration in the residential segment would reach 6% in 2015

split systems. Little and not invasive solutions have been preferred in order to fulfil sporadic heatwaves; the economic aspect has had importance too. The importance of moveable devices is more emphasized if we consider that 60% of sold units are for the residential sector. Since Germany is more a commercial market, sales of splits for domestic applications are very low and this consideration decreases once again the different position covered by moveable and split solutions in the global market. In other words, in the German context, positions covered by splits and portable equipment are comparable in terms of sales, while a huge gap between the same is recorded in Spain and Italy. Another consideration that emerges from Figure 98 is the increase that moveable and split products had experienced during the five-year period between 2005 and 2010. Besides the international financial crisis, the air conditioning market developed with a growth rate of about 50%; specifically, on one side, split systems recorded a progress of +60% of units sold, and on the other side moveable sales grew of about 64% in terms of volume.

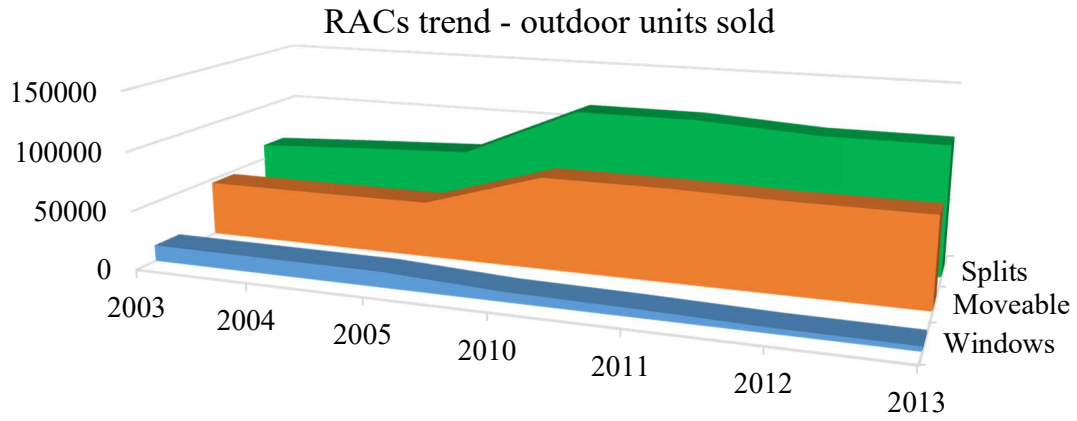


Figure 98 - German RACs trend (Source: BSRIA and JARN)

Residential/Light commercial market, volume of outdoor units										BSRIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	47000	47000	*47500*	*47500*	*48000*	*48253*		78000	78000	76000	76000
Windows	13600	13400	*13300*	*13200*	*13100*	*12978*		8330	7000	4600	4000
Ductless-Splits	63100	68000	*72264*	*76430*	*81706*	*87266*		116000	116000	110000	110000
Grand Total	123700	128400	*133064*	*137130*	*142806*	*148497*		202330	201000	190600	190000

Table 22 - German Residential/Light Commercial Market (Source: BSRIA and JARN)

Moveable devices' market is significant and it is supposed it might further improve, especially in the case of hot summers and heatwaves. Split devices should experience an increasing penetration, in the residential sector too. An important progress has been recorded

in the commercial category, where VRF takes the dominant position in terms of value. Market value moved from 236 US$ million in 2004 to 312 US$ million in 2013; speaking of VRF, the increment was from 67 to 156 US$ million in the same period. Nevertheless, VRFs are mainly installed in offices, shops and leisure centre, more than half of the total in new construction. However, the important aspect that emerges from the improvement of mini-splits in the commercial segment is that they "are view as high quality, high performance products and this will ensure their further popularity for the 'carbon neutral' homes of the near future envisaged in German legislation"[86]. Perhaps the JARN's declaration is quite excessive, it is symbolic of the fact that split equipment should play a relevant role also in housings. In the end, according to BSRIA data, all mini-splits are sold with inverter drives and the majority of the products (70%[87]) are in the configuration only cooling.

	splits market (million $)		outdoor units sold		average market price	
	2004	2013	2004	2013	2004	2013
single	129,6	125	56750		2284	
multi	39,6	31	7500		5280	
VRF	67	156	3750		17867	
total	236,2	312	68000	110000	3474	2836

Table 23 - German Splits Market Evolution (Source: BSRIA and JARN)

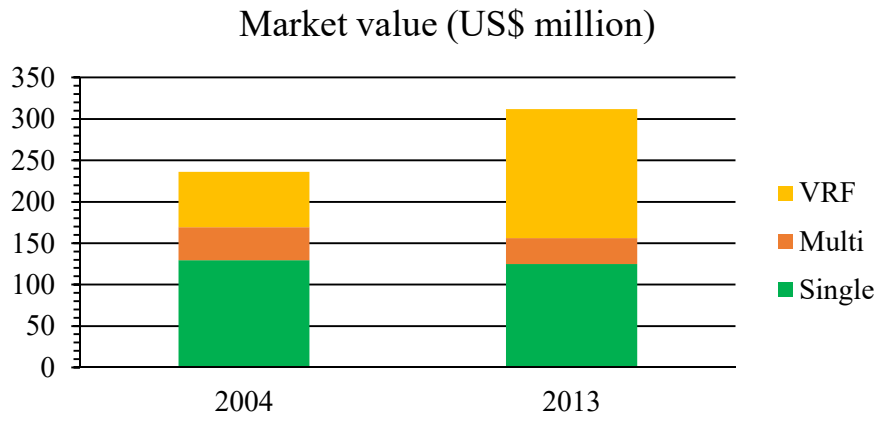


Figure 99 - German Market Value (Source: BSRIA and JARN)

Air conditioning share of package solutions is inconsistent in the residential sector and, therefore, is out of the scope of the present study. Furthermore, because of limitation due to economic and dimension aspects, they are product that not matched with the housing's requirements. On the contrary, different conclusions are obtained for hydronic cooling.

[86] *JARN, May 25, 2013*
[87] *BSRIA data, Europe Report, April 2005*

Specifically, radiant cooling systems cover the 30-40% of the new buildings' cooled space and their role becomes larger in the residential heating segment. Since the past decade or even more, radiant panel alternative has experienced a relevant growth, eroding a big share of radiators in the national heating market[88]. Underfloor heating has reached lot of popularity thanks to key aspects as low energy consumption and high comfort level. While the German heating demand is permanently decreasing and therefore radiators' market is dropping, UFH and in general radiant technology is in a privilege position. Indeed, a part from favourable factors as the fulfilling of energy saving and high comfort requirements, they find advantage of the building regulations' spreading, which promoted an huge decreasing of residential consumptions as well as suppling the same with an increasing penetration of renewable sources. In this contest, radiant solution is acting a significant role.

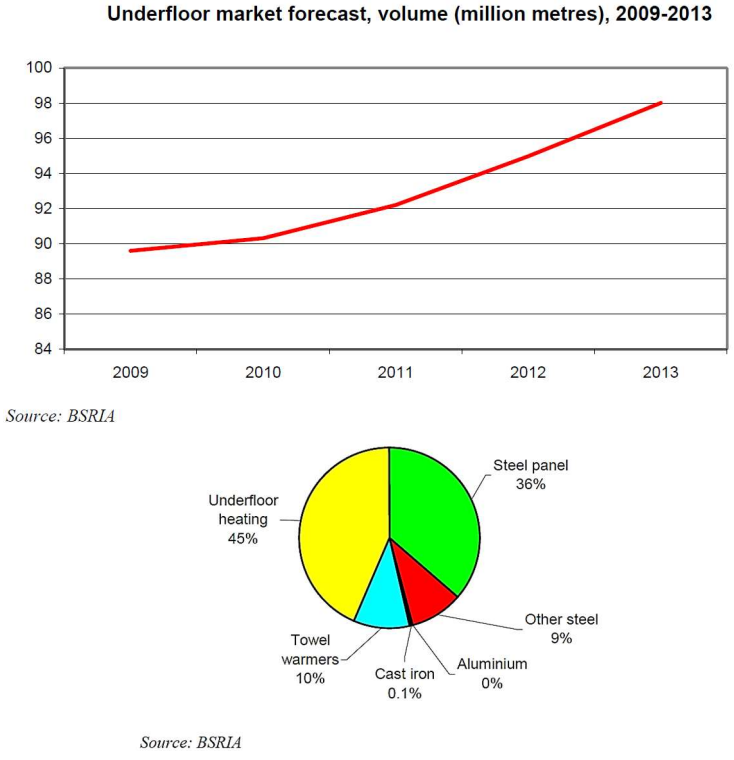


Figure 100 - German UFH Penetration (Source: BSRIA)

Over the 80% of the residential stock is equipped with collective/individual central heating systems. Speaking of heat generator types, the most common ones are gas and oil boilers, which together cover the 80% of the existing stock; for multi-family houses district heating plays a significant role, while heating from electricity and, in particular, from biomass is quite important for single-unit ones. Other heating systems' presence is small currently, but

[88] According to BSRIA, in 2009 the market share of radiant panels was around 45% for space heating

some alternative solutions, like heat pumps and wood pellet boilers, are experiencing an ascendant tendency in the market. In particular, in 2011, German heat pumps' market was of 57,000 units sold, 32,600[89] of which were in ATW configuration. It is confirmed by *JARN, August 25, 2012* journal that the market of heat pumps, and especially the ATW's one, is improving in Germany. Beside the international financial crisis and in particular the high electricity price, between 2011 and 2012 European Heat Pumps association recorded an increase in volume of 4% for space heating and 20% for DHW applications. ATW gained a market share of 62.7% and they are becoming more popular, especially in newly built single or two-family houses. Specifically, households well perceive the combination of the same with photovoltaics as an independent heating solution. Even if the development of electricity prices is an evident barrier to an even higher market share of heat pumps, the factors that might positively influence the ATW and GSHP evolution are several. For instance, national development and incentive scheme, as *Marktanreizprogramm* and *EEWärmeG*, are stimulating the use of more efficient and environmental friendly systems. These two guidelines consider a certain amount of energy from renewable sources in new residential edifices, as well as for existing ones, and issues subsidies in order to promote high efficiency heat pumps as renewable generators. Furthermore, heat pump solution can be also integrated in mechanical ventilation systems, which are supposed to have a huge effect in the future nZEBs and passive houses. The speed with which these kinds of new buildings would spread in the next fifteen years should be relevant in Germany, since "German end users are generally prepared to pay higher prices for environmentally friendly products"[90].

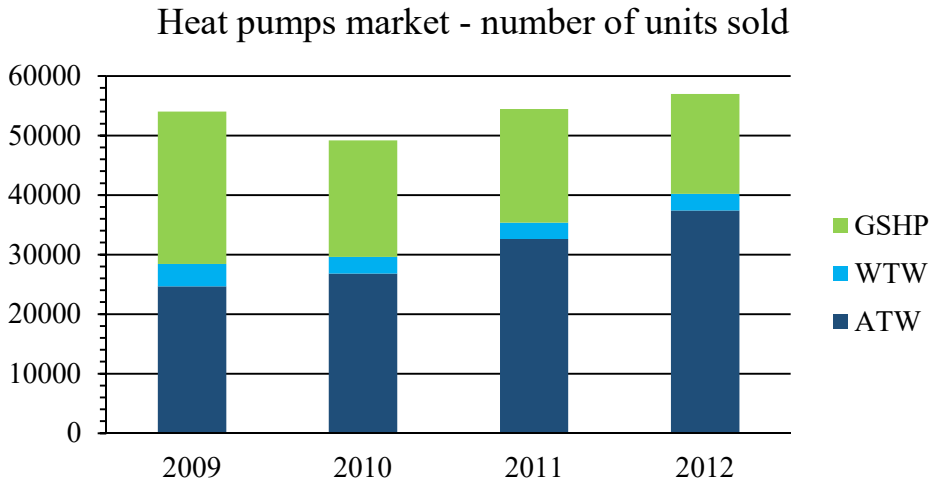


Figure 101 – German Heat Pump Market (Source: European Heat Pump Market and Statistics Report 2013)

[89] According to *JARN, August 25, 2012*, the 57% of sales was air-to-water applications
[90] *BSRIA Radiators and Underfloor Heating, Germany, World Heating 2009*

Heat Pumps Type	2009	2010	2011	2012	2010/2012 evolution
ATW	24664	26796	32616	37400	39,57%
WTW	3782	2834	2758	2800	-1,20%
GSHP	25589	19525	19089	16800	-13,96%
ATA	0	0	0	0	
Total	54035	49155	54463	57000	15,96%

Table 24 - German Heat Pump Market (Source: Heat Pumps Market and Statistics 2013)

CONSIDERATIONS

Germany is one of the smallest residential air-cooling market in Europe, while the penetration of air-conditioning devices is quite high (55%) in the commercial sector. Nevertheless, from data collected, a rapid progress in the domestic cooling demand is evident and Germany represent a fundamental potential cooling scenario. Economic stability, as well as optimistic forecast for residential construction industry, the copious population and the current low penetration of indoor-cooling in houses are the perfect background for a privilege and profitable future market. The increase of cooling demand is driven mainly by the development of residential comfort requirements as consequence of better wealthy conditions reaches by citizens. However, factors like wealthy and comfort desires should emphasize their huge impact in case of summer temperatures might become more severe. As confirmed by Figure 102, hot and torrid summers are becoming more frequent. Cooling demand should be not a luxury matter anymore, but a necessity and the desuetude to face up to extreme warm summers would lead people to a furious race toward air cooling systems' purchase.

In this scenario, the technologies' role is expected to change; moveable devices are supposed to leave the market because of the strong competition of splits and some hydronic solutions. Splits, on the contrary, might improve their positions thanks to their cheapness, availability, awareness, installation facility and extreme adaptability of each kinds of applications. Nevertheless, also alternative products, such as radiant panels, should cover fundamental roles in the next few years. Since this technology is experiencing a huge progress for space heating, it should become more relevant for space cooling too. Currently radiant cooling covers over the 30% of new buildings' cooled space. The combination between a reversible-renewable generator and the radiant technology, with high probability, should give to the same a great opportunity on the forecast market. Moreover, because of summers which are not characterized by excessive humidity levels, radiant cooling matches perfectly with the kind of requirements for the considered season. In the end, German households are wealthier and more incline toward efficient solutions; this is the reason why radiant cooling should play

a more relevant role in Germany than in other Countries where one of the main driven factor is related to cheapness.

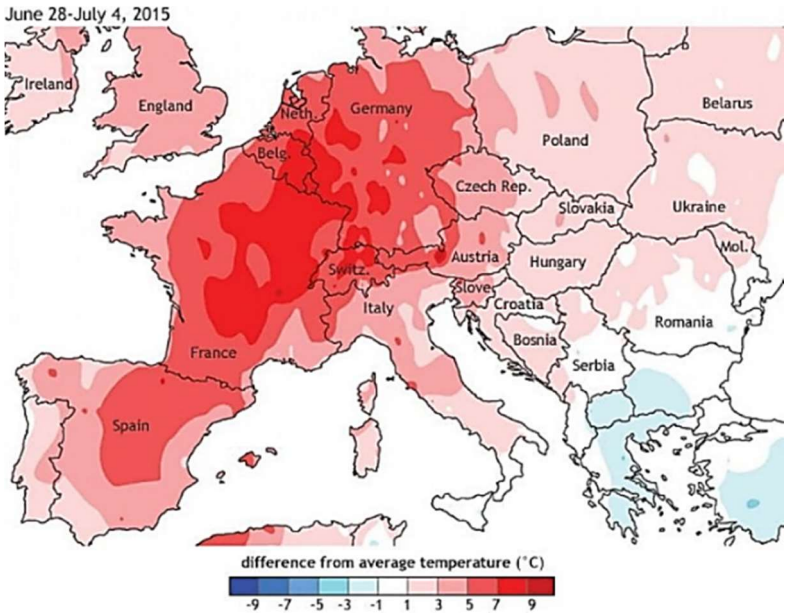


Figure 102 - Temperature Anomalies (Source: Wikipedia – Temperature Anomalies 2015)

FRENCH CASE

With an estimated population of around 67 million[91], France is the third most populated Country in Europe, after Russia and Germany. The Nation's importance is further perceived if one considers that France is the fifth world economic Country and it is over the threshold of 30,000 € of GDP per capita[92]. The Nation has experience a positive economic growth during the first years of the new millennium, reaching its lowest unemployment share of 7% between 2007 and 2008. Nevertheless, France has recorded a huge recession period since 2009, because of the mortgage crisis. Whilst the scenario has remained more favourable than in other EU Members, it is evident that the Eurozone crisis has led to some negative effects, specially talking about the residential construction industry. The latter registered a decline of 4.2% in 2010, which has been steady up to now with poor demands of new constructions. On the contrary, before the international financial crisis, the same sector had experienced a strong growth, with an activity level of around 4 million[93] new residential buildings between 2000 and 2008. The domestic segment has been the most prolific for the construction industry, accounting for the 44.3% in 2013[94].

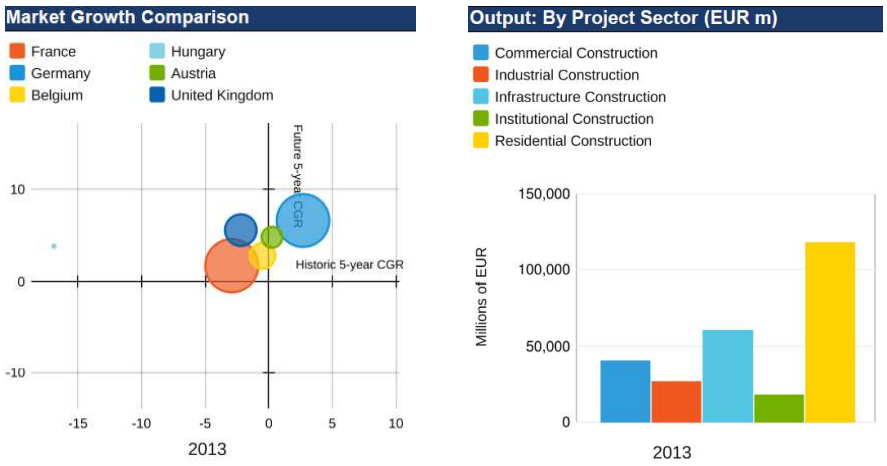


Figure 103 - French Construction Industry (Source: Construction Intelligence Centre – France)

However, the French construction industry covers a significant position in terms of market dimension, but statistical data on the same are not much positive. In the period analysed by *CIC*, French industry recorded a negative CAGR of around -3% between 2008 and 2013, and their forecasts are weak and lower than the ones supposed for English and German sectors.

[91] According to Wikipedia the French population in 2015 is 66.917.994
[92] Eurostat data, French GDP pro capita = 32,400€ in 2014
[93] ENTRANZE project, France
[94] Construction Intelligence Centre data

In particular, the French residential segment is expected to register a CAGR of only 0.48% over the forecast period, reaching an output value of EUR 121.8 billion by 2018. It is evident that also for the next few years a deep impact due to slow-moving economy and high unemployment rate (over 10% in 2015[95]) is supposed, leading the housing market to a stagnant or weak evolution. In order to overcome this negative situation, the French government has developed a new housing scheme, the "Buy to Let", with which the authorities hope to trigger a rapid recovery on new residential constructions or, in general, the housing market. However, institutions are quite confident because, as *CIC report* confirms, the new habitations' demand is high in France since citizens are more incline to build or buy a new own house instead of renting. *The challenges, dynamics and activities in the building sector and its energy demand in France* shows the breakdown of ownership of the existing building stock in France; the 80% of inhabitants living in a single-family house are owner of the dwelling, while the share of the same is just around 22% in multi-family block. Most of national apartments are rent or are social dwellings.

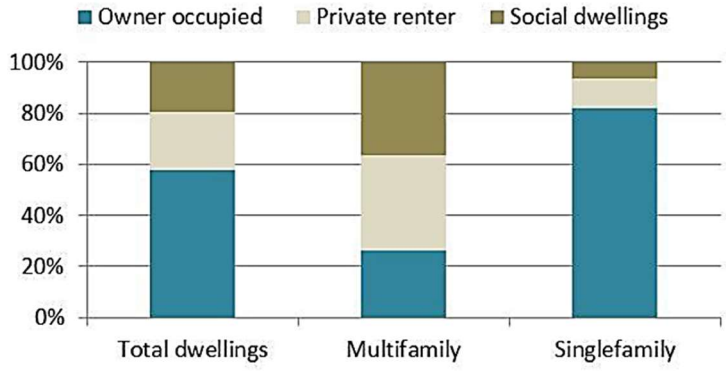


Figure 104 – French Buildings Social Breakdown (Source: ENTRANZE project)

Single-family dwellings account for the 57% of the total amount[96]. Beside their relevant presence in the existing domestic stock, single-family market account for the 48.8% and it has recorded a negative CAGR of -1.99% in the five-year period between 2008 and 2013, in which its value reaches EUR 58 billion. The single-unit segment is the one which is expected to be deeper influenced by the national status of high unemployment rate, rising interest rates and budget deficit; a forecast CAGR of -0.17% is estimated. On the contrary, the multi-family class was the fastest-growing category in the past period and it is described by

[95] Wikipedia data
[96] In terms of buildings, single-unit and terraced edifices account for the 92% of the total number of buildings

more optimistic forecasts. According to *CIC*, the apartment's market value is projected to move from EUR 60.9 billion in 2013 to EUR 64.3 billion in 2018.

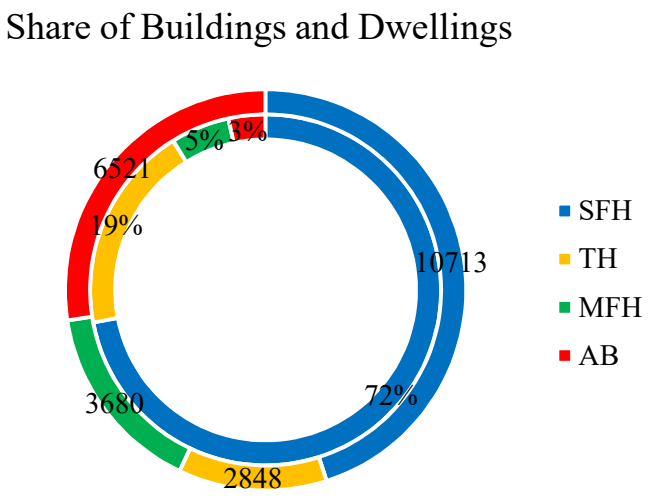


Figure 105 - French Share of Buildings and Dwellings (Source: TABULA project)

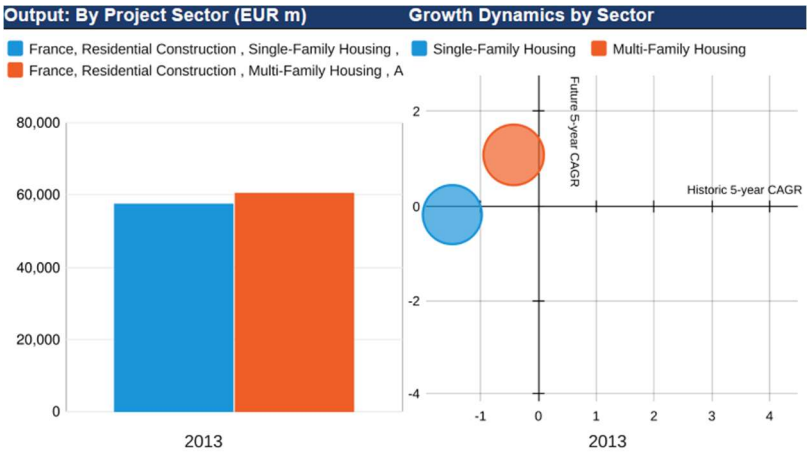


Figure 106 - French Construction Industry Outputs (Source: Construction Intelligence Centre)

It is clear, therefore, that new residential constructions difficulty might influence the air cooling market for a further important recovery; on the contrary, the potential of the existing buildings stock is more promising. Figure 106 shows that the 43% of the dwelling stock existing in 2008 was erected after the first thermal regulation adopted in 1975 and that habitations built in the new millennium account for the 14% of the global national amount[97]. Data on the French buildings stock are available:

[97] TABULA project data

- Number of buildings: around 15 million
- Number of dwellings: 33.1 million
- Average dwelling sizes:
    - SFH: 112 m^2
    - MFH: 66 m^2

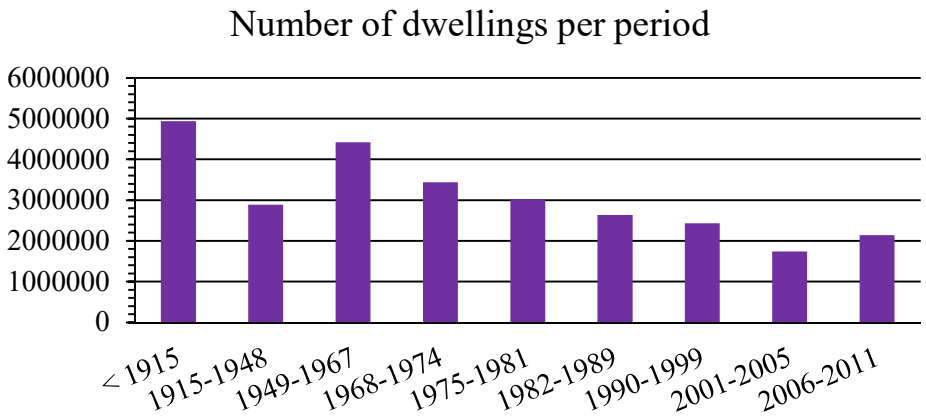


Figure 107 - French Construction Periods (Source: TABULA project)

percentages related to building numbers of the respective classes SFH I - MFH II				
Percentage of modernised element area (with improved thermal protection)				
Building classes	SFH I	SFH II	MFH I	MFH II
	until 1975	1975-2000	until 1975	1975-2000
walls	37	88	19	52
roofs / upper floor ceilings	62	90	25	65
basement / cellar ceiling	12	42	10	30
windows*	35	75	23	57

Table 25 – French Percentage of Modernised Element Area (Source: TABULA project)

Analysing *TABULA project* data, one fundamental result highlights a significant activity toward the requalification of the French stock. Table 26 describes the percentage of buildings that has been under refurbishment in order to improve their own thermal performances. What comes first to eyes is that high values are referred to the single-family categories of both two construction's periods, before and after the first building thermal regulation. Specifically, a 90% of single-family habitations erected between 1975 and 2000 are equipped with modernized roofs and upper floor ceilings; moreover, the 88% and 75% of the same has improved thermal protections respectively for walls and windows. Lower percentage values are registered for multi-units segment since it easy to understand that

households living in apartments have less economic capacities. In addition, also the complexity of refurbishment or renovation on dwellings block is more complex than in a single house.

As previously stated, France experienced an interesting increase in the buildings cooling field in the first years of the new millennium, especially thanks to the development in the commercial sector. Unusual high temperatures in summer and the huge heatwaves in 2003 triggered the French market, which evolved speedily reaching the 55% of penetration in the service sector in 2004. Governments and local authorities have promoted the importance of air conditioning in the first years of 2000s, in order to prevent any of the misfortunes experienced in 2003. As a result, indoor air-cooling equipment started to be more frequent also in habitations; the residential segment was subject of the indoor cooling expansion too, even if with a low growth rate. According to *Solarcombi+* and *JARN* information, the share of domestic edifices equipped with air conditioning devices was 6% and 9% respectively in 2004 and 2013. It is clear that the development of the market has been quite steady as concern the residential category and this result is attributed to the deep impact of the financial crisis. Figure 107 shows two different trends, a strong increasing one in the 3 years period between 2003 and 2005 and a feeble negative evolution in the last five years. The heatwave and the economic crisis have caused double effects in this scenario. While hot summers pushed the mini-splits sales to over 500,000 units in 2004, reaching a market value of US$ million 959.1 in the same year, the Eurozone crisis had affected negatively, reducing sales to 300,000 mini-splits in 2013, that is to say US$ million 590[98].

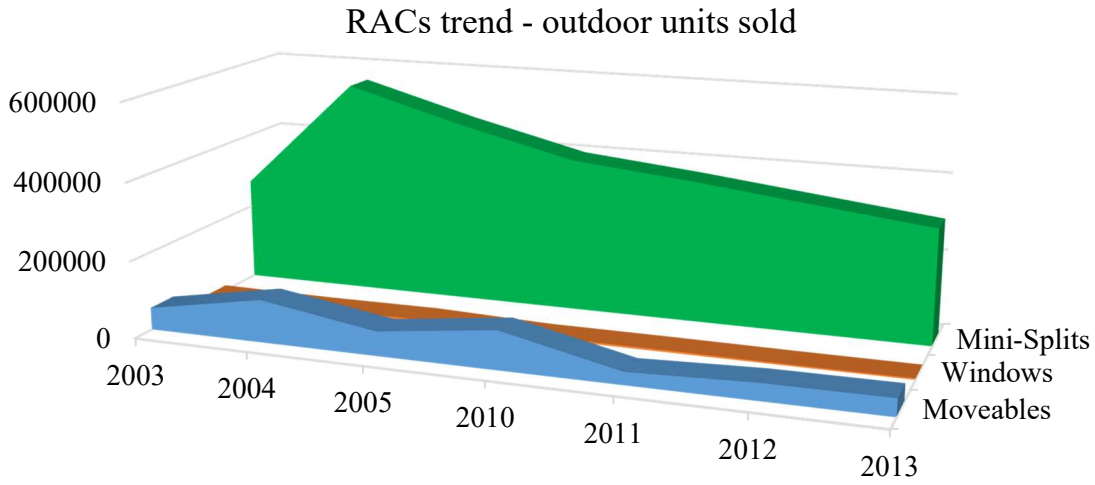


Figure 108 - French RACs Market (Source: BSRIA and JARN data)

[98] *BSRIA Europe Report and JARN journal, May 25, 2013*

N° of air conditioning systems in dwellings	SHF I	SFH II	MFH I	MFH II
N° dwellings (x1000)	412.9	355.1	116.5	100.1

Table 26 - French AC Penetration (Source: TABULA project)

Residential/Light commercial market, volume of outdoor units										BRSIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	57000	110000	*62791*	*65931*	*67909*	*70965*		100000	33000	44000	45000
Windows	14000	12000	*13721*	*13721*	*13447*	*13314*		5000	5000	3800	3800
Ductless-Splits	270300	556900	*473532*	*520287*	*587962*	*642610*		400000	370000	335000	300000
Grand Total	341300	678900	*550044*	*599939*	*669318*	*726889*		505000	408000	382800	348800

Table 27 - French Residential/Light Commercial Market (Source: BSRIA and JARN)

The two main RACs are mini-splits and moveable devices; windows' elements are effected by a strong competition and, therefore, their market is decline since many years. No forecast are supposed and many manufactures are pushing window configuration out of their portfolio. On the contrary, moveable products have a good reputation in the Country and this is confirmed by the fact that France is one of the three main European market for the same. Nevertheless, while the sales of movable and split systems, in terms of volume, are not so different in the German contest, the gap between the same in France is more evident. On one side, moveable products have been installed mainly for residential applications and their market has been deeply influenced by climatic reasons. From Figure 107, it emerges that moveable equipment's market has been fluctuating in the past decade, and BSRIA and JARN reports have recorded some picks just after the hottest summers. On the other side, mini-splits cover the most significant position in the RACs' market, mostly thanks to the commercial sector development. Indeed, splits became very popular in the light commercial segment and they are sold mainly in heat pump configuration. VRF arrangement have seen a steady and quite rapid growth in volume and value in the same category. However, an increasing use of split solution is recorded also for domestic application due to the swelling of the residential cooling demand.

	splits market (million $)		outdoor units sold		average market price	
	2004	2013	2004	2013	2004	2013
single	690,6	262,5	450000	320000	1534,67	1281,25
multi	210,8	147,5	98000		2151,02	
VRF	57,5	180	8900	15000	6460,67	12000,00
total	958,9	590	556900	335000	1721,85	1761,19

Table 28 - French Splits Market Evolution (Source: BSRIA and JARN)

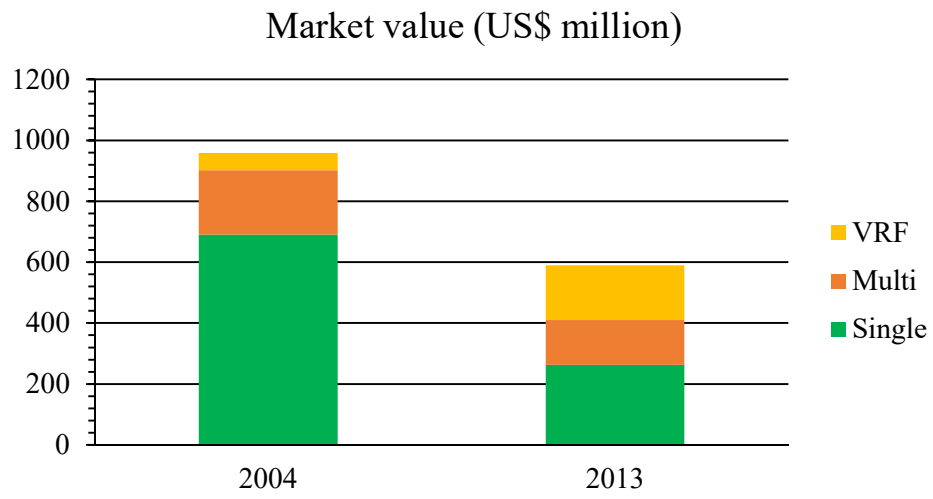


Figure 109 - French Splits Market Value (Source: BSRIA and JARN)

Taking into consideration the complexity to face up with hydronic cooling systems, as fan coils and radiant panels, the present study has decided to move the attention from final elements to generators, as chillers and heat pumps. Analysing the market of the latter two elements, one should figure out the position they have covered in the residential cooling demand up to now and forecast which should be further evolutions in the same field. In particular, both *BSRIA Europe Report* and *European Heat Pump Market and Statistics REPORT 2013* underline the increasing tendency in France toward installations of chillers and, in general, of heat pumps for space heating and cooling. The former document reports some data as 8,500 chillers sold in 2012 and ¾ of sales in ratings of less than 100kW; all these information are useful for BSRIA to highlight the tendency toward small-scale chillers as demonstration of the residential cooling demand's development inside the Country. On the other hand, JARN affirms that in 2011 French ATW market scale was estimated at 55,300 units[99]; although the economic recession and drastic cuts of national incentives, ATW heat pump has showed a positive trend as confirmation of the high awareness of the product. However, a huge drop was recorded compare to 100,000 units sold[100] in 2009. A survey of low-energy buildings in France shows that heat pumps are the most common for space heating with a share of 36%, and it is important to stress that half of the same are in air-to-water configuration, while one third uses geothermal energy.

[99] *JARN, May 25, 2013*
[100] *European Heat Pumps Market and Statistics - 2013*

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	106543	53854	55299	54214	-49,12%
WTW	2973	1627	1703	1295	-56,44%
GSHP	6969	2968	3589	3593	-48,44%
ATA	30115	34597	34279	31709	5,29%
Total	146600	93046	94870	90811	-38,06%

Table 29 – French Heat Pumps Market (Source: Heat Pump Market and Statistics 2013)

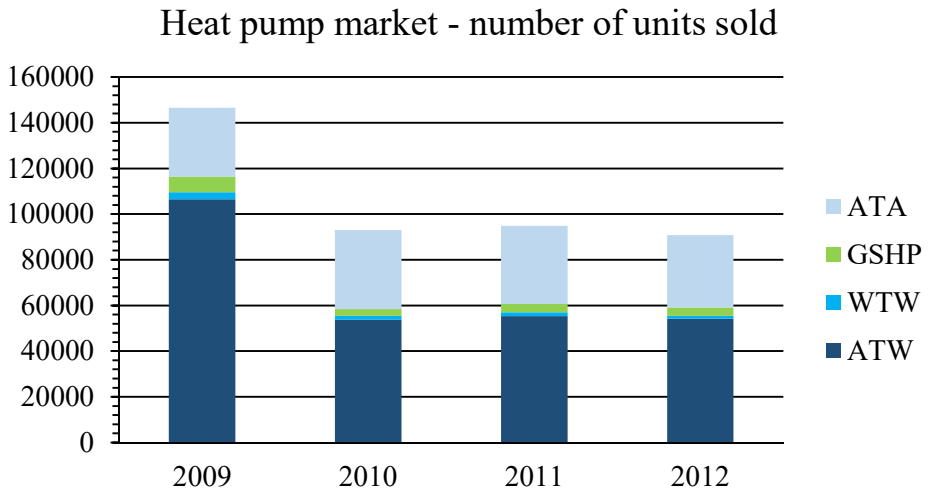


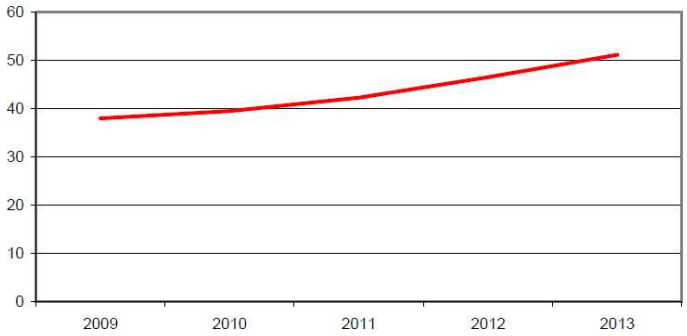
Figure 110 - French Heat Pump Market (Source: Heat Pump Market and Statistics Report 2013)

The rapid evolution of the heat pump sector, mainly for the ATW category, has gone to the same speed of the radiant market; some statistic data demonstrate that radiant panels are becoming popular as main solution for space heating in the residential segment[101]. 8 million m^2 of floor coils were installed in France in 2011; "most of these were for heating, often associated with heat pumps, although some were used for heating and cooling"[102]. Thanks to the this positive trend, radiant technology is gaining more position also in existing buildings, promoting wall-coil systems which ensure simpler installation and even more potential if used also for cooling. In conclusion, one should affirm that nowadays the hydronic technology has not a relevant position in the residential cooling market, but positive improvement are supposed thanks to the strong development of combined systems heat pumps-radiant panels for space heating. As heat pumps are becoming more popular as alternative solution to traditional boilers, radiant panels are expected to record a huge increase of penetration in the

[101] According to *Radiators and Underfloor Heating - France,* the share of UFH is 44% if consider the global market of radiators and radiant panels.
[102] *JARN, August 25, 2013*

heating market, since they are the equipment that better matches with renewable generators. Because of this, many radiant plants should be sold in order to fulfil at the same time the housing heating and cooling demand, in both configuration UFH&C and wall-coils.

Figure 3.2 Underfloor market forecast, volume (million metres), 2009-2013



Source: BSRIA

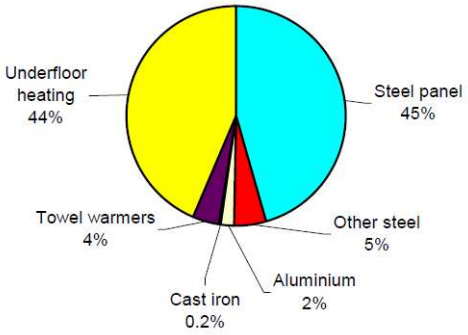


Figure 111 - French UFH Penetration (Source: Radiators and Underfloor heating, France)

CONSIDERATIONS

France was an emerging cooling market during the most prolific years after 2000. The service sector has developed fast reaching an air conditioning penetration over 50%; on the contrary, the spreading of air-cooling devices was lower in the residential segment, although the government has emphasized the importance of the same after 2003's heatwave. Nowadays the market is still quite immature, but it has strong potential for a further growth. The most significant influences should come from climatic and economic conditions. In particular, other sever summers as the 2003's one should stimulate several sales in the field, especially regarding residential applications. Speaking of which, the current season (summer 2015) is predicted as one of the hottest since many years and it would be interesting analysing the consequences of the same.

Together with weather, wealthy is fundamental too; the economic recovery should be essential in order to stimulate households' purchases. French population is aware about the importance of cooling, especially in the Mediterranean regions, and better economic conditions might put sales on the same level of pre-crisis one. As confirmation of that, JARN journal *May 25, 2013* affirms that penetration of air conditioning is expected to reach 24% in 2016.

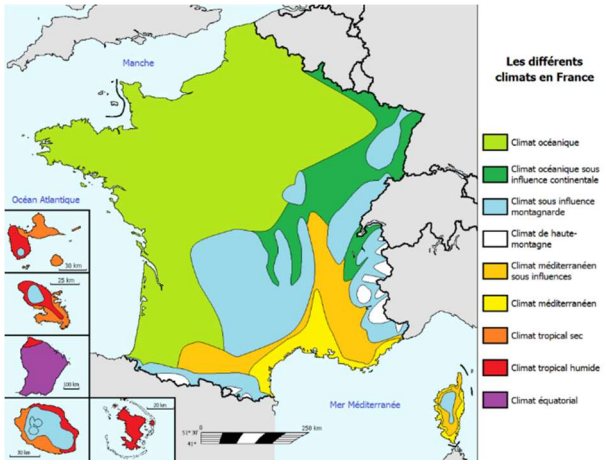


Figure 112 - French Climate (Source: Wikipedia)

On one side, the present study thinks that split solution would be the most popular as cooling device. The reasons of this are recognizable in cheapness, facility of installation mainly in existing edifices and adaptability of each climatic requirements. The majority of these products would be on heat pump configuration, so mini-splits are expected to cover a relevant role both for housing heating and cooling. On the other hand, the diffusion of ATW is strong and they are gaining much reputation as replacement of traditional boilers. It is evident the labour that many manufactures are doing, promoting hybrid solutions (boiler + heat pump) and developing systems that meet the relatively high temperatures required by traditional radiators. The forecasted of ATW heat pumps' high penetration is supported also by European directives' transpositions, which, on one hand make renewable energy mandatory for individual housing and, on the other hand, are promoting ATW and GSHP as necessary alternatives in order to achieve green energy saving requirements. Indeed, "the objective for France is to reach 2 million individual housing heated by heat pumps in 2020"[103]. The huge evolution of ATWs' market is the main driver that should lead hydronic cooling to play a more relevant role in the next few years. This is the reason why radiant panels might be a fundamental product, able to meet at the same time the combination of heating and cooling, as well as a great compatibility with low temperature heat pump generators.

[103] *European Heat Pumps Market and Statistics REPORT 2013*

ENGLISH CASE

Probably, the UK case seems to be not so essential for the scope of the present study. Nevertheless, it has been decided to develop a short analysis also for the English instance in order to better understand which are the potentials of the same Country toward residential air cooling field. Nowadays, the penetration of such systems in the domestic segment is very low, approximately around 3% according to JARN data. The climate is temperate, moderated by prevailing southwest winds over the North Atlantic; because of this, in all parts of the Nations is needed space heating for a long period that comes from October until April, while at the moment air cooling seems to be unnecessary or just a matter of luxury. However, since UK is not a maturated market in the field, it represents at the same time one of the most potential if higher temperatures would become more frequent. *Radiators and Underfloor Heating – United Kingdom, 2009* affirms: "it is expected that due to climate change the UK will face a rising sea level, higher temperatures, and more frequent floods and storms". Warmer seasons should have a relevant impact on households spending, triggering a rich air conditioning market. Indeed, one should remember that the United Kingdom's population is around 62 million and it is supposed to have a huge increase in the following decades. Furthermore, UK is the sixth economic Country in the world, just after Germany and France, and its GDP per capita is over the threshold of 30,000€.

Residential/Light commercial market, volume of outdoor units										BSRIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	62445	58074	*54009*	*57249*	*62974*	*68642*		39000	26000	18000	10000
Windows	4800	4800	*4900*	*5000*	*5100*	*5200*		800	800	600	600
Ductless-Splits	156700	189573	*181071*	*194523*	*204249*	*214461*		175000	171000	168000	165000
Grand Total	223945	252447	*239980*	*256772*	*272323*	*288303*		214800	197800	186600	175600

Table 30 - English Residential/Light Commercial Market (Source: BSRIA and JARN)

The English market of air conditioning is strongly based on the service/commercial sector, reaching high penetration around 42% in 2013[104]; therefore, commercial applications have influenced the majority of sales, in terms of products' typologies. This is the reason why the market is dominated by splits solution and specifically the role covered by VRFs is the most significant one in all Eurozone. In 2013, indeed, VRF's sales were around 15,000 units

[104] *JARN, May 25, 2013*

and their market share was about half of the global, that is to say around US$ 240 million. Moreover, VRF systems have helped up well in the recession, maintaining mini-splits market steady through the period of analysis, mainly in terms of value[105]. As just said, while the value of single split solution has decreased, VRFs have gained a more significant position in the scenario of air conditioning, as demonstration of the importance of the commercial category.

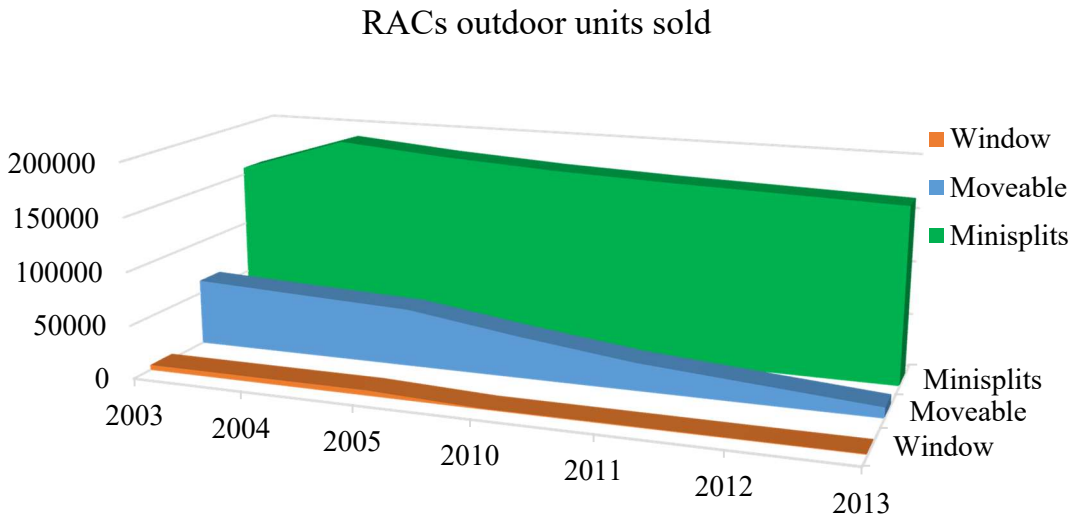


Figure 113 - English RACs Market (Source: BSRIA and JARN)

	splits market (million $)		outdoor units sold		average market price	
	2004	2013	2004	2013	2004	2013
single	305,9	226,4	171505	150000	1783,62	1600,00
multi	19,5	13,6	7785		2504,82	
VRF	173,7	240	10283	15000	16891,96	16000,00
total	499,1	480	189573	165000	2632,76	2909,09

Table 31 - English Splits Market Evolution (Source: BSRIA and JARN)

Speaking about the residential sector, it is mainly based on moveable technology since the same has better met the households' requirements. Moveable products has remained a popular short-term fix for cooling during sporadic spells of hot temperatures in summer. The combination of quick and simple use, as well as cheapness and the possibility to keep it in the utility room, has made these systems the most suitable for English dwellings. However, because of the economic crisis and the lack of warm seasons during the past few years,

[105] According to BASRIA and JARN data, in 2004 the market of split systems was around US$ 500 million, while in 2013 it was about US$ 480 million

moveable equipment's sale have reduced; nevertheless, if there would happen some external factors, mainly climatic changes, moveable and split solution are supposed to play the most significant roles in the residential air cooling market.

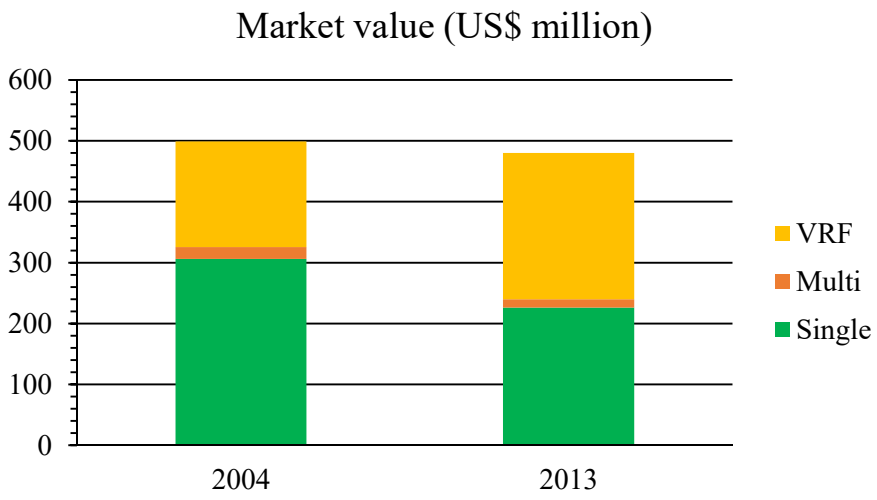


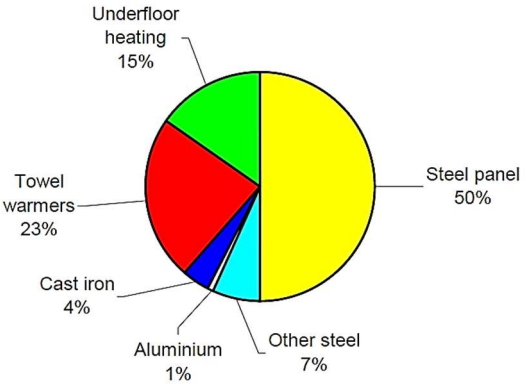
Figure 114 - English Market Value (Source: BSRIA and JARN)

Together with the economic analysis, an overview on the building stock and industry should be useful in order to figure out other considerations that might have some impacts on the market. First, it is fundamental to consider that the existing stock is around 27 million of edifices, 22 million of which are on single/two family configuration. This result is essential to underline how single-unit houses are prevalent in the English contest. Individual central heating is the most popular kind of installation in UK, since, as BSRIA affirms, "house owners living in single-family dwellings tend to have an individual boiler … rather than sharing a larger plant for several dwellings, as often in the case of larger multi-dwellings buildings". Specifically, the 76%[106] of the overall heating systems are gas boiler. As the majority of the EU Members, English heating distribution element are mostly hydronic radiators.

While UFH systems have become more popular especially for commercial and industrial installations, connected to the market evolution of heat pumps, radiators are supposed to be the most common product, even because many manufacture are developing new low-temperature solutions which seem to be very competitive and suitable not only in new and existing building, but also with alternative generators. On the other side, an increasing number of suppliers are implementing some sales' scheme in which they will sell heat pump

[106] *Radiators and Underfloor Heating, United Kingdom - BSRIA*

and radiant panels as a combined solution in order to decrease the price. This is the reason why underfloor heating should go on improving its market share in the new building segment. As concerns heat pumps, and in general alternative generators, their market is expected to remain very small compared to the huge boilers' one, although ATW are going to maintain a growth trajectory in the coming years.



Source: BSRIA

Figure (Source: Radiators and Underfloor Heating – UK)

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	8325	11840	12765	14455	73,63%
WTW					
GSHP	3980	3850	2255	2294	-42,36%
ATA	4150	3050	3480	1050	-74,70%
Total	16455	18740	18500	17799	8,17%

Table 32 - English Heat Pump Market (Source: Heat Pump Market and Statistics, 2013)

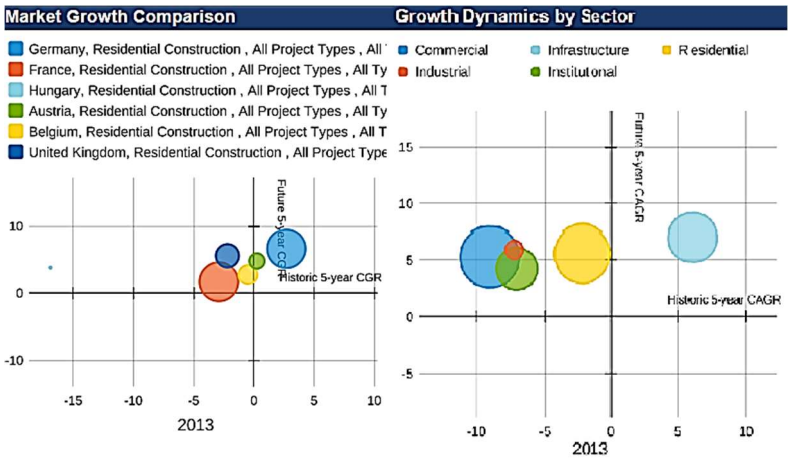


Figure 115 - English Construction Industry (Source: Construction Intelligence Centre)

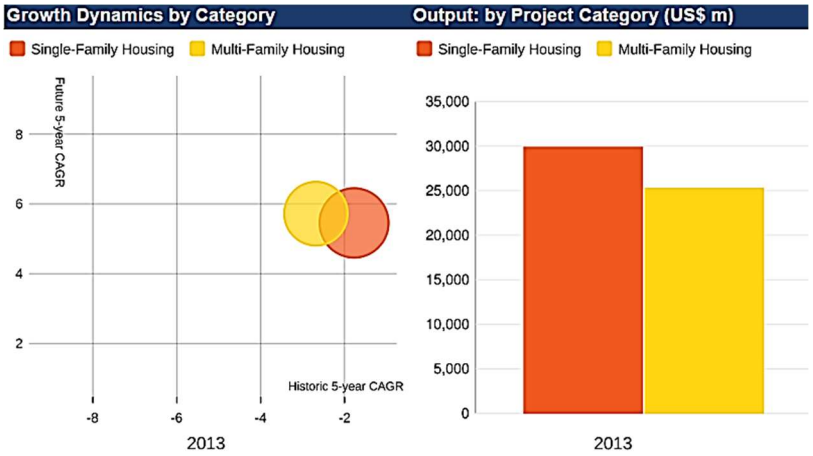


Figure 116 - English Residential Construction Industry (Source: Construction Intelligence Centre)

Both heating and cooling markets are influenced by the construction industry, which, according to *CIC*, is showing signs of recovery in the last 2 years, due to fundamental supports by government that is investing mainly in the infrastructure and housing sector. With a share of 40%, the residential segment was the largest in UK in 2014, reaching a value of US$ billion 89.9 in the same year. As in the past five-year period, single-family and multi-units categories are supposed to grow with same rates, with a common forecast-period CAGR of 5.90% to value US$ billion 110.8. *CIC* affirms that the housing demand is increasing thanks to low interest rates, falling unemployment, increase in wages and population growth.

RUSSIAN CASE

The Russian air cooling market emerged in the early 1990s and nowadays it represents one of the highest potential in Europe, given the size of the State. The Russian market has yet an own structure, based on both commercial and domestic demand. The market moved into residential sector in 1998 and it has developed mainly through room air conditioners. Window devices recorded strongest success in the first years of the new millennium and specifically in the Southern Russia, in rural areas and outskirts of large cities. The reasons of this development deals with economic aspects. As just said, South Russia is the region where an air-cooling system should be considered essential or at least fundamental in case of hot summer. However, this is also the area with lower income for the population and this factor has driven the demand toward low-price climate equipment, as 1.5 kW models. Nevertheless, sales of windows experienced a drastic reduction from 80,000 units in 2011 to over 45,000 units in 2012. It is clear that this negative trend is strongly correlated to normal variabilities of the Russian cooling market, but the most relevant cause deals with the strong competition given by split application. This is the reason why windows are expected to exit from many manufactures' portfolio. Moveable products play an important role too since they meet requirement of sporadic spells of hot. Their evolution has been correlated to climatic conditions; sales increased every hot summer and then decreased in case of unfavourable temperatures. For instance, the hot weather affected the sales of moveable equipment, which shot up from 42,000 units in 2010 to 150,000 units in 2011. As consequence of what just explained, moveable systems should maintain an important position on the market and sudden peaks are supposed in case of heatwaves.

RUSSIA	Gen	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dic	Wint	Spr	Sum	Aut	Year
Tm.max	22,2	29,8	30,3	34	37,7	43,2	45,4	43,5	41,5	33,7	29,1	25	23,7	34	44	34,8	34,1
Tm.min	-71,2	-64,4	-60,6	-46,4	-28,9	-9,7	-9,3	-17,1	-25,3	-47,6	-58,5	-62,8	-66,1	-45,3	-12	-43,8	-41,8

Table 3433 - Russian Seasonal Average Temperatures (Source: Wikipedia)

Residential/Light commercial market, volume of outdoor units										BSRIA	JARN
	2003	2004	*2005*	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	6000	9000	*12000*	*12500*	*13000*	*13000*		42000	150000	80000	140000
Windows	115000	121000	*130000*	*150000*	*140000*	*130000*		80000	80000	45000	30000
Ductless-Splits	320100	350000	*405000*	*496000*	*602000*	*716000*		1000000	3100000	2000000	2000000
Grand Total	441100	480000	*547000*	*658500*	*755000*	*859000*		1122000	3330000	2125000	2170000

Table 35 - Russian Residential/light Commercial Market (Source: BARIA and JARN)

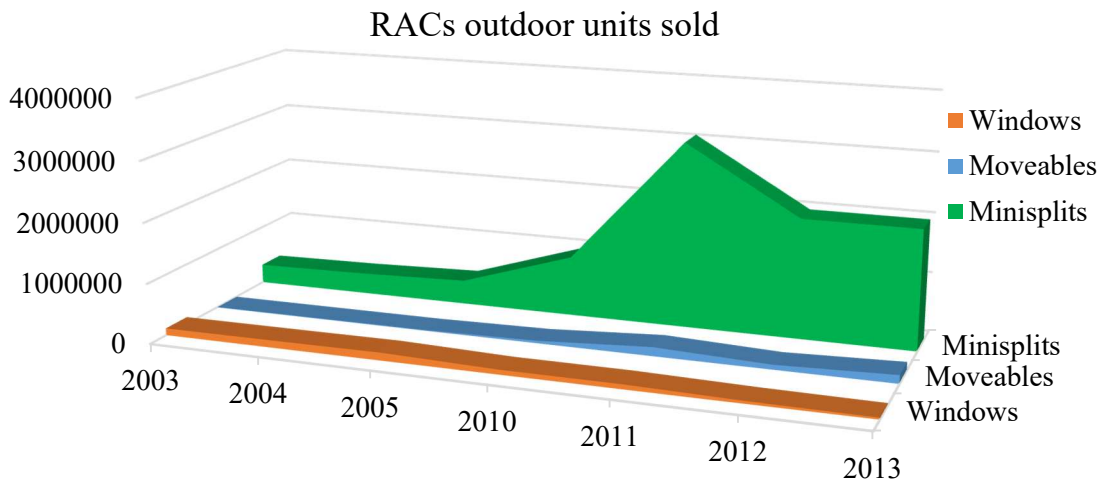


Figure 117 - Russian RACs Market (Source: BSRIA and JARN)

The numbers of outdoor units sold gives the most significant result, showing at the same time the Russian big potential and its strong instability due to climatic variations. One should easily identified the huge increase that mini-splits experienced between years 2010 and 2011. According to JARN statistic data, in 2011 splits sales reach 3.1 million units and US$ billion 1.7[107]. It was an unexpected and extraordinary success if one considers that the number of units sold were over the best Italian and Spanish results. This peak was the consequence of an unusual hot summer in 2010 during which temperature did not go under 30°C for many days. Due to the subsequent panic through the Russian population, the majority of households decided to equip their own house with such equipment; for instance, near Moscow number of sales increased four times in 2011. The success of mini-split solution has been granted by cheapness and high awareness's level of citizens, but also by applications' typologies. The product has been suitable to every kind of demand and use. Split systems ensure good comfort conditions and the fulfilment of the same should be decided instantaneously. Moreover, one should not forget the economic aspect, as well the great adaptability to each building typology; the one considered is a systems that is appropriate both for existing and new houses; no differences are present in terms of single-family or multi-unit applications. Due to the low reliability of the local district heating systems, Russian consumers prefer to install split systems with heat pumps and valve for reverse cooling/heating cycle. Currently the market is quite steady, although it is over the threshold of 2 million of unit sold and US$ 1 billion[108] and single splits dominate the same. Multi-split and VRF configurations are still perceived as too

[107] *JARN, May 25, 2013*
[108] Idem

expensive for both domestic and service applications. Thanks to this market volume, Russia temporarily became the fifth largest air conditioner market after China, US, Japan and India.

The Russian example is useful to underline the impact that weather changes should have in a big potential Country. Abnormally hot temperatures during summer 2010 have been sufficient to trigger one of the most potential market in Europe, which has reached sales over European previous records yet. Beside some economic influences also effected the Russian scenario, the necessity to face up with unusual hot temperatures has led households to a frenetic research of cooling applications.

The fundamental role of Russia is accentuated by the high potential of its market, given the size of the Country; European Russian population is around 100 million, that is to say about the 70% of the global Russian one[109]. Furthermore, the housing stock in Russia amounted to 20 million buildings of the total floor space 3.177 billion m^2 as of 2009 year end. Between 2000 and 2009, the existing stock grew by 14%. The 72% of the residential buildings are located in urban areas and the 70% of the global floor area consists of housing units in apartment blocks. Specifically, multi-units edifices were estimated to account over 3 million, while individual houses equalled to around 16.5 million. Another significant data concerns the ownership breakdown: *Russian urban housing energy efficiency programme – model development* declares that in 2009 the majority of households are owner of their dwellings for a share of 84% of the existing stock. In particular, the share breakdown is 97% for single-family edifices and 76% for apartment blocks, as confirmation that households that live in multi-family buildings are for the 25% of cases renter of flats. Russia' housing stock of apartment buildings is in desperate need of capital repairs.

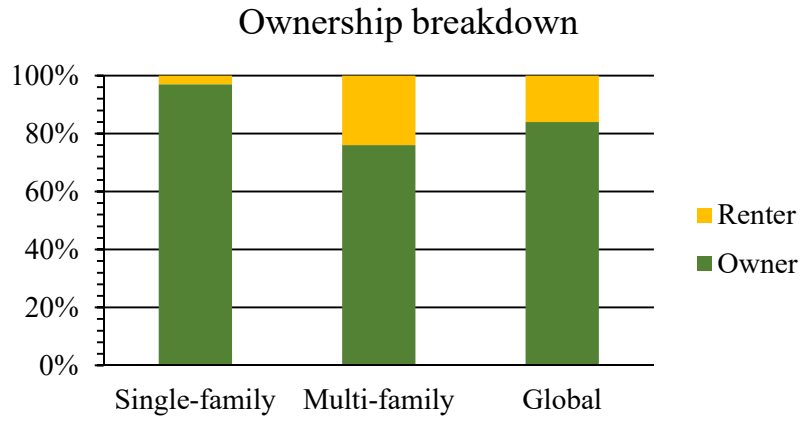


Figure 118 - Russian Housing Breakdown (Source: Russian urban housing energy efficiency program – model development)

[109] Wikipedia data

A part from current Country's dimension size, another important external factor that should stimulate a further strong development on splits' sales is related to the great growth of the construction industry. As one should immediately recognize from the following data, the Russian construction industry is recording a positive trend since many years; the review-period between 2008 and 2013 is characterized by a CAGR value of around 4%, superior to German and American results. The two main categories that give a great contribution to the construction industry are infrastructure and housing ones; private and public investments supported the growth registered. According to *CIC*, the residential segment was the second largest one in terms of outputs, accounting for the 23% of the total construction market value in 2013. It has recorded a past CAGR of around 10%, reaching in 2013 a value of US$ billion 60.1. The factors that have had a positive impact on the domestic segment are several and they are supposed to going on favouring further improvements of the same in the next few years. In particular, the study wants to mention the expanding middle-class population and urbanization growth, as well as the increasing levels of income and low unemployment rate, which is among the lowest in the word. Thanks to the increasing housing demand, the report previously mentioned estimates a forecast-period CAGR of 6.67% to value US$ billion 76.3 in 2018. Figure 120 shows that the single-family segment is the largest in terms of market value, since it accounts for the 62.8% of the total in 2013, that is to say US$ 37.7 billion. On the other side, in the same review-period 2008-2013, the multi-units buildings category has been the fastest growing category. Thanks to positive factors previously listed, such as the expanding middle-class and the growing urbanization, both sector are supposed to improve further by 2018, with CAGR of 5.98% (US$ 46.4 billion) for individual houses and 7.81% (US$ 30 billion) for apartment blocks.

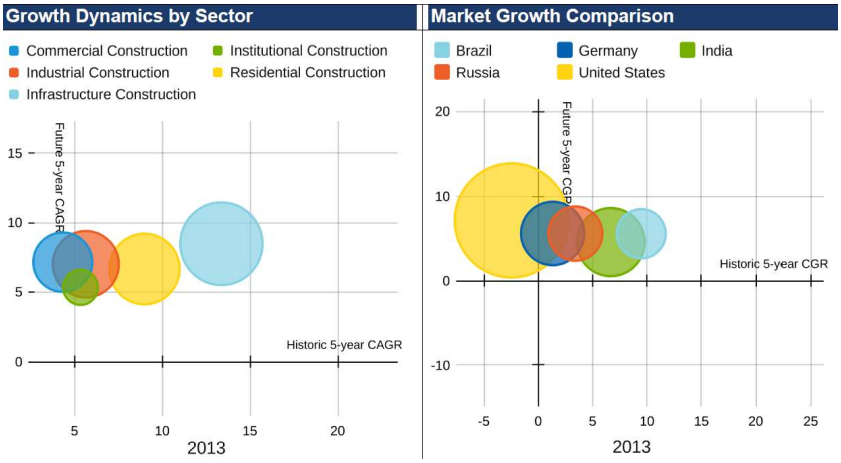


Figure 119 - Russian Construction Industry (Source: Construction Intelligence Centre)

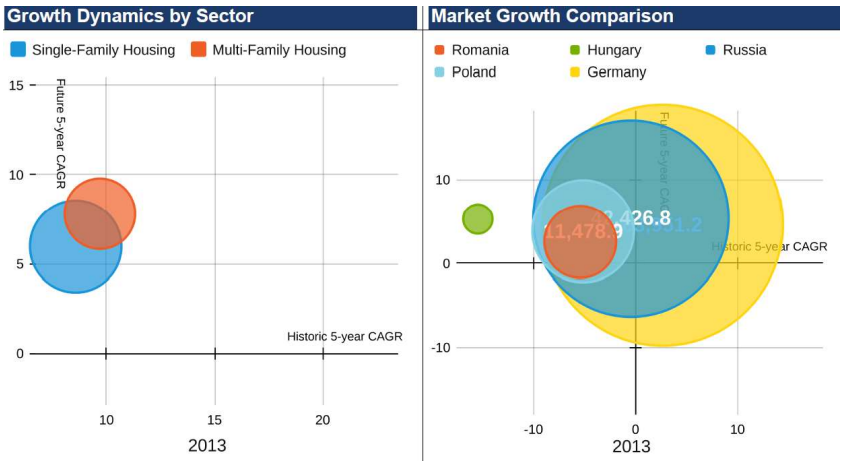


Figure 120 - Russian Residential Construction Industry (Source: Construction Intelligence Centre)

Hydronic systems for cooling supply are absent in the Country since no information and data are reported on them. Nevertheless, as done for other EU Members, an analysis of the national hydronic technology is useful in order to figure out shares and roles played by the different products regarding space heating. There is a correlation between how much a system is used for heating and its consequence role for space cooling too. The present revision thinks that, especially for hydronic alternatives as FCUs and radiant panels, some cooling application should increase their share in the global air conditioning offer by improving their reputation in the heating field. Nonetheless, the Russian case is quite particular since the national hydronic heating systems is strongly based on radiators and on gas' use as main fuel. Furthermore, district and collective heating networks still cover the 74% of all dwellings. However, *Radiators and Underfloor Heating – Russia* describes the same as low-quality distribution systems, since many problems in terms of control and water quality are registered. This is the reason why the Russian government is promoting programs in order to improve the heating systems by converting some district networks to collective and individual heating systems in new constructions and big renovation projects. The document previously mentioned declares that the share of individual heating plants is currently increasing, supplying 1/3 of the total new residential buildings; district network is still prefer as solution in case of apartment blocks in larger cities.

Radiators are the most common emitters in Russian houses for all configurations of heating distribution. The underfloor heating technology, according to BSRIA, covered the 30% of the radiator and UFH's market 2009, but if one considers the basic model of equivalent radiators, the share of the same is just 5%[110]. Indeed, underfloor heating is a niche market for

[110] *Radiators and Underfloor Heating - Russia*

new residential luxury edifices, with an average size of at least 200m^2 [111]. Moreover, given the rigid Russian climate during winters, radiant panels are especially used as support of other heating emitters. In many regions, a part from the Southern ones, radiant technology is not sufficient to fulfil the global heating load required from the household, and this is the reason why panels are installed preferably in bathrooms, kitchens and/or living rooms, as complement to radiators. However, the market of UFH is expected to develop further and opportunities also for radiant cooling are mainly in the Southern zone of Russia.

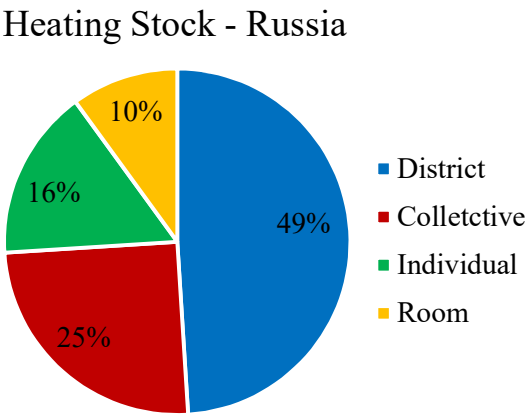
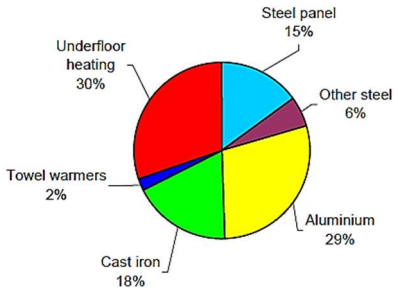


Figure 121 - Russian Heating Scheme (Source: Radiators and Underfloor heating – Russia)



Source: BSRIA

The underfloor heating market forecasts, volume (million metres), 2009-2013

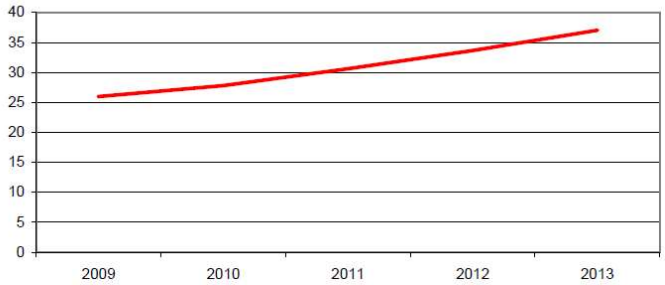


Figure 122 - Russian Radiator and UFH Market (Source: Radiators and Underfloor heating – Russia)

[111] Idem

TURKISH CASE

Turkey is recognized as an emerging country among European Members, since its economy has shown remarkable performance of growth over the last decade. Although the financial crisis has hit hugely the Turkish economy, the Country has been able to weather the recession better than others, thanks to government spending increasing and announced temporary tax cuts. Furthermore, many incentives schemes have stimulated the construction industry, which has been the main driver of economic growth during the past period. The construction market has improved through the last five-year period, accounting in 2013 for US$ 83.7 billion. It is supposed that public and private investments should push a further development mainly in the residential, institutional and infrastructural sectors, which have been up to now the most prosperous. Thanks to these supports, the construction industry might record a forecast CAGR of 8.07%, by value US$ 115.6 billion in 2018[112]. The residential segment accounted for 51.4% in 2013, that is to say US$ 43 billion. However, an expanding middle-class and population describe Turkish scenario, which are stimulating a strong demand of houses among the Nation. In addition to these, also economic improvement for households, rising incomes and the urbanization trend are inspiring a constant and positive development on the housing industry, which therefore is expected to improve their market value with a prospective CAGR of 7.63%, that is to say US$ billion 58.3. In 2013, multi-units category covered the 94.6% of the total residential outputs, and it was the fastest growing one during the period of analysis between 2008-2013. This is a demonstration that in Turkey there is a strong tendency toward urbanization, which is supposed to drive the segment into consideration to a forecast improvement by reaching a market value of US$ 55.2 billion in 2018 from US$ billion 40.7 in 2013[113]. Single-family houses account for the 5.4% of the market in 2013 and *CIC* affirms that their value is expected to move from US$ billion 2.3 to US$ billion 3.1 in the same forecast-period, that is to say a future CAGR of 6.87%. Another influencing factor deals with the fact that Turkish households prefer to own houses, instead of renting the same.

Through the past fifteen years, the residential industry's development has supported the expansion of air-conditioning products in the same sector. Even if in the first years of 2000s the penetration of air-cooling for houses was not high, BSRIA in 2005 predicted a positive tendency of the same in the following period. Indeed, as confirmation of the solid

[112] Construction Intelligence Centre
[113] According to CIC the forecast CAGR for multi-family houses is 7.67%

mechanism of improvement of the cooling market, JARN affirms that the penetration of indoor equipment was around 30% in 2013 and it is probable the same should increase further year by year. Considering the Turkish geography, and so climatic characteristics of the different regions, the territory is divided in three areas:

- The Mediterranean coast and the one on the Aegean Sea are described by hot and dry summers and mild winters.
- The coast on Black Sea has an oceanic climate, with warm summers and cold winters, both humid.
- In the middle of Turkey, the climate is continental, that is to say hot and dry summers and rigid winters.

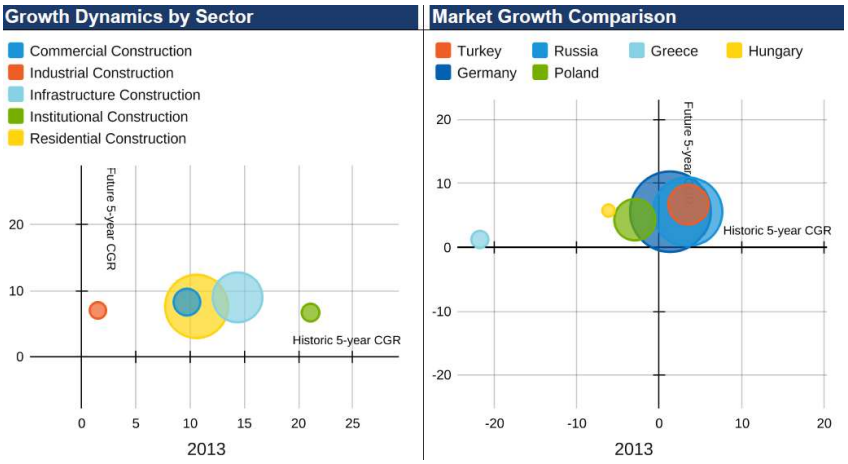


Figure 123 - Turkish Construction Industry (Source: Construction Intelligence Centre)

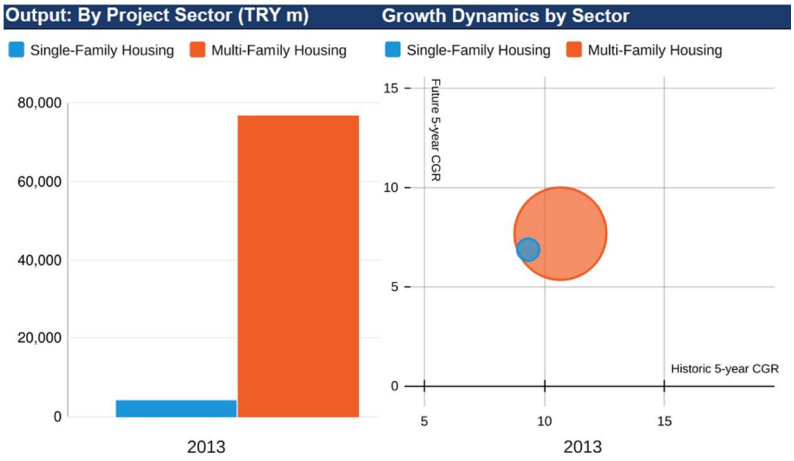


Figure 124 - Turkish Residential Construction Industry (Source: Construction Intelligence Centre)

Until the end of 1990s air conditioning was just a matter of luxury and wealth; currently, having an air-cooling in a house is quite a necessity, or at least is more common than in the past. One should just remember that new Turkish offices have chilled air emitters as standard requirement, as well as hotels are obliged to have the same under a national regulation. This one aspect confirming the spread awareness and consciousness toward air-cooling in houses too.

Hence, one should recognize several factors that could have influenced the positive trend of air conditioning market in the past decades, and together with the construction industry growth, previously explained, the present study thinks it is important to consider also the relatively good economy and the strong affirmation of tourism in the Nation. GDP per capita, for instance, after having recorded slower growth rate during the economic recession period, grew over 11,000€ in 2013, that is to say +8%[114]. Moreover, the Turkish population is one of the fastest expanding one in Europe: in 2003 it was under the threshold of 70 million of citizens, while in 2014, according to Eurostat, the number of inhabitants was over 76 million. In other terms, the current housing stock accounts for 7.6 million of residential edifices, which means about 20 million of dwellings (72% of total floor area is covered by multi-family houses).

Taking all into consideration, the present survey is useful to emphasize the increment that the air-cooling market has recorded since 2000. In particular, the present study would like to stress the potential that Turkey has for a further increase of air-conditioning products' sales, which are expected to go on following an ascendant direction thanks to positive influences from the growing population and urbanization, as well as the improvement of construction industry and households' economic conditions. As in many other Mediterranean countries, the Turkish market has developed basing itself on the split configuration. While windows disappeared from offers and just some replacements should stimulate their sales, moveable are maintaining a marginal role in the market, especially for domestic applications. Moveable products have become more popular in the past few years, thanks to an increasing cooling demand due to favourable hot temperatures.

Residential/Light commercial market, volume of outdoor units										BSRIA	JARN
	2003	2004	2005	*2006*	*2007*	*2008*	2009	2010	2011	2012	2013
Moveables	680	612	581	*552*	*525*	*498*		1700	6600	9000	10000
Windows	2700	1800	1400	*1200*	*1100*	*1000*		0	0	0	0
Ductless-Splits	433910	526321	613049	*714197*	*832182*	*969833*		688000	835000	1000000	1100000
Grand Total	437290	528733	615030	*715949*	*833807*	*971331*		689700	841600	1009000	1110000

Table 34 - Turkish Residential/Light Commercial Market (Source: BSRIA and JARN)

[114] Eurostat data

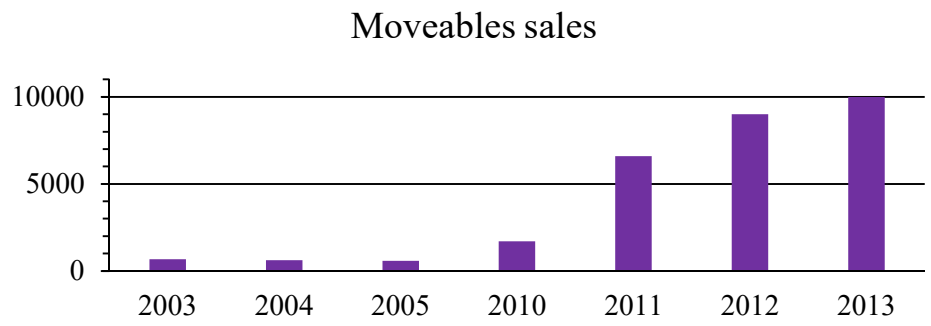


Figure 125 - Turkish Portable Devices Market (Source: BSRIA and JARN)

	splits market (million $)		outdoor units sold		average market price	
	2004	2013	2004	2013	2004	2013
single	454,9	530,4	507961	1045000		
multi			17500	55000		
VRF	12,4	149,6	860			
total	467,3	680	526321	1100000	887,86	618,18

Table 35 - Turkish Splits Market Evolution (Source: BSRIA and JARN)

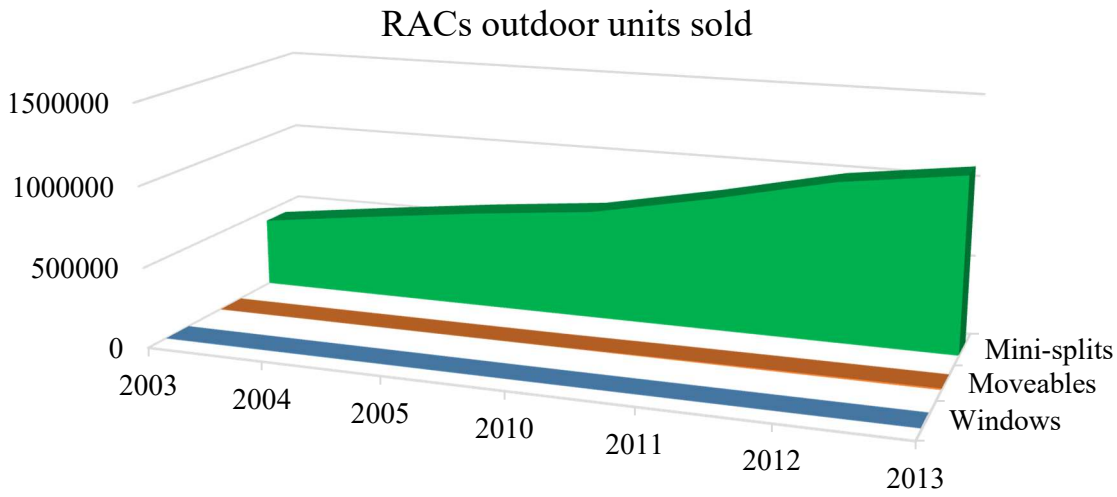


Figure 126 – Turkish RACs Market (Source: BSRIA and JARN)

Mini-splits have dominated the air-conditioning market, gaining the most significant position in both commercial and residential sector. While the main European markets have experienced negative tendency also for splits' sales because of the huge impact of the economic restriction, Turkish evolution of the same was positive, reaching in 2012 over one million units sold. Single splits are predominant in terms of volume, accounting for the 95% of the same. From an economic point of view, VRFs covered the 22% of the global market

value in 2013 and JARN journal declares: “this is a market sector expected to have a double-digit growth over the next few years”[115].

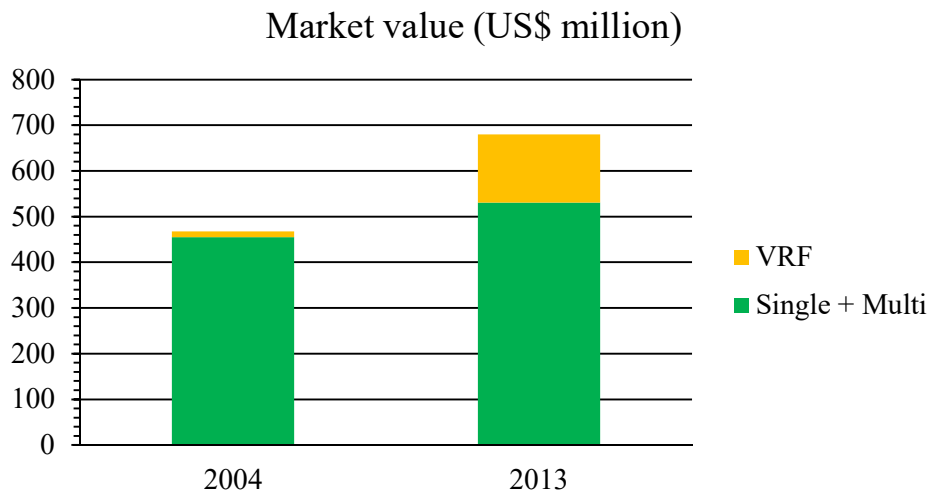


Figure 127 - Turkish Splits Market (Source: BSRIA and JARN)

The main aspect that pushed the split solution over the others is the economic one and this is more evident in the Turkish scenario. During the new millennium’s beginning, the average price of small split systems was between US$ 270 and 500, installation included. The installation of such equipment was cheap and, from 2000 to 2005, the total price dropped up to 50%. Furthermore, as confirms by *BSRIA European Report*, “manufactures, distributors and agents have teams which are providing installation service as well as the after sales service which is becoming an important market tool”. In other words, with a low-price investment, households had the possibility to purchase a good air-cooling system, easy to install in every kind of dwellings and suitable to each climatic zone, comprehending also many further services, as just described. Hence, the combination of great adaptability and cheapness have made split technology the predominant one both for commercial and residential air-cooling task and are maintaining the same on the top position in the market also in the following decade.

[115] *JARN, May 25, 2013*

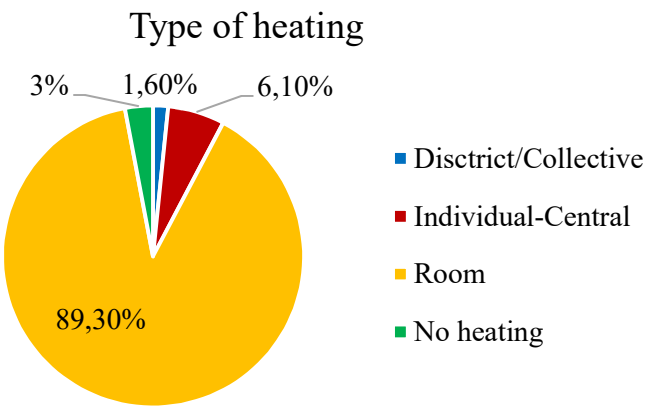


Figure 128 - Turkish Heating Scheme (Source: Radiators and Underfloor Heating – Turkey)

As concerns hydronic cooling, or at least the diffusion of chillers and heat pumps, there are no relevant signs in the Turkish scenario since they are technologies that have not developed own markets inside the Country. For instance, it is significant that in 2009 only 61 of the 80 Turkish cities were supplied with the gas network for housing space heating. Moreover, although the government is still working in order to expand the same, it is said that coal and wood are more common solutions used for the same purpose because of economic reasons. Therefore, it is evident that heating plants are not so innovative as well as the gas network, and data above emphasize this aspect further: room air heating equipment heat the 90% of the existing dwellings. There is a trend in the country in order to promote individual central heating boilers, thanks to the spreading of the gas network, necessary to improve the national heating scheme. These are the reasons why many of the most advanced systems, as heat pumps and radiant panels, have difficulty to increase their presence in the Turkish market. The progress of some innovative solutions is anyway inevitable, but at the same time very slow since the meagre actual status. For example, Turkey has great potential in terms of renewable sources, as wind, ground energy and solar power. Due to also low prices and availability, solar thermal panels and PV collectors are on the rise as many households in the South of Turkey use these units for the DHW and electrical demand.

SWEDEN – NORWAY – FINLAND – DENMARK CASES

The following chapter has the purpose to give a description of the Scandinavian Countries in order to figure out which are the potential opportunities for air-cooling products. It is clear that many obvious barriers are impeding the development of the same and one in particular is the climate. The Scandinavian summer temperatures are at least around 20°C, especially in the South of the peninsula, while the condition in the Nordic areas are more rigid even during 'warmer' seasons. However, it is true that some unusual heatwaves have been registered, for example in Finland, when in the summer of 2006 temperatures were over the threshold of 30° for several days. A part from sporadic spells of hot climate, the mild-cold specifics of the same are the main driver of low evolution of air-conditioning market. Furthermore, one should also consider that the Scandinavian market size is not so tempting, since the global population accounts for 20 million[116]. Simultaneously, they are the richest Members with GDP per capita over the European average value. On the other side, the rising attention toward nZEB in the Scandinavian Peninsula should become a trigger factor for the mechanical ventilation and cooling market, both for private and public buildings. However, many doubts are still present regarding nZEB, in the Nordic Countries too. For instance, even if they have similar climatic conditions, they seem to define 'nearly-zero energy buildings' in quite different ways, as a result of historical different building regulation and different energy supply systems. This is a consequence of the EPBD directive, which affirms that the methodology adopted from Nations may be differentiated not only at national level, but at regional one too.

- A recent study from the Norwegian Energy Agency shows that there are substantial barriers for the realization of passive house, and even more for nZEB in the national building regulation. However, heat pumps and solar thermal collectors are identified as main on-site production of renewable energy.
- Sweden's Energy Agency and the National Board of Building and Planning have two different opinions/definitions of nZEB; the former believes that an nZEB has half of the energy consumption declared on the existing building regulation, while the latter is convinced that current buildings already meet such energy performances requirements.

[116] Norway: 5 million - Sweden: 9.5 million - Finland: 5.4 million

Therefore, it is difficult to predict if the evolution of lower-energy edifices should introduce a new cooling market's development since many reservations are still present concerning the real energy performances of the same, as well as a potential cooling demand. The question now is if ever the market should grow, which will be the predominant technology? It is very hard to give a common answer for all the Scandinavian Countries since many differences are identifiable in the energy supply systems as well as the national space heating scheme. For example, Sweden and Finland are two of the strongest European market of heat pumps and is it probable that their propensity should interact with air-cooling systems' choices.

SWEDEN

The Swedish scenario is described by an existing building stock made by 1.896 million of dwellings in single/two-family houses and 2.502 million of apartments in multi-unit buildings. It is a rich country and its GDP per capita in 2013 was around 33,000€. Another important data concerns with the share of renewable energy in the national source's mix, which was around the 56% in 2011.

However, Sweden is a mature market for domestic heat pumps, which are now in use for more than 50% of Swedish individual houses. According to JARN heat pumps are most common solutions chosen for new single-unit habitations and for refurbishment of the same too. Nevertheless, Martin Forsén affirms in *JARN, August 25, 2012* that the Swedish market is experiencing a stagnant period because of the first stage of saturation; sales of all type of configurations, air-to-water, exhaust air and GSHP, are decreasing since some year. On the contrary, the multi-family sector is attracting great interest from the market, even if the share of the same supplied by district heating is over the 80%[117].

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	15941	13120	8958	6384	-59,95%
WTW				18	
GSHP	27544	31954	31384	24502	-11,04%
ATA	60000	70000	55000	55000	-8,33%
Total	103485	115074	95342	85904	-16,99%

Table 36 - Swedish Heat Pumps Market(Source: European Heat Pumps Market and Statistics)

[117] According to *European HP Market and Statistics REPORT,* 82% of total flats are supplied by district heating

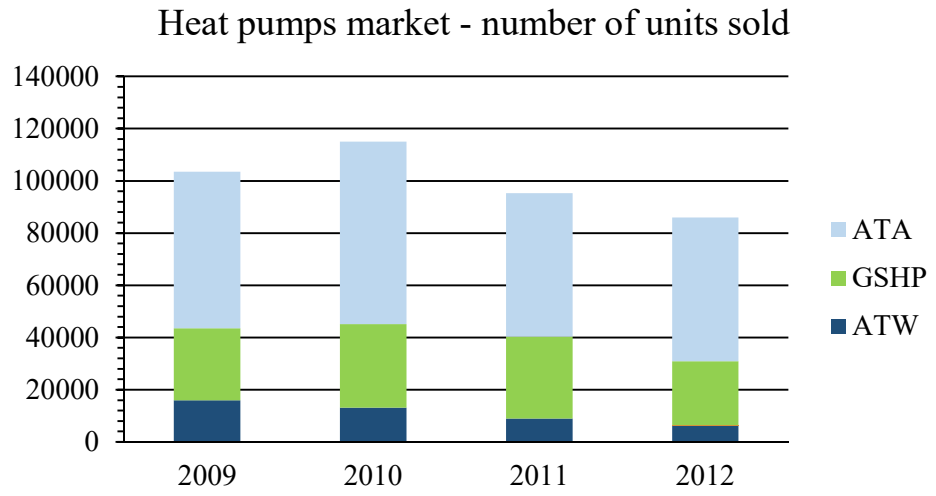
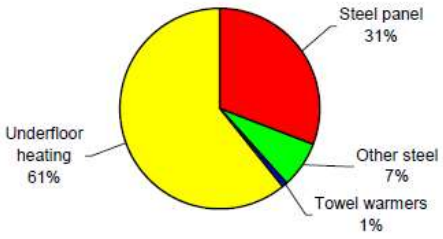


Figure 129 - Swedish Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

The primary configuration systems of heat pumps are air/air (58%) and ground source heat pumps (26%)[118], as confirmation of the general trend of Nordic Countries toward GSHP. Air/air systems, that is to say single splits, are mainly installed in existing houses, often used to complement direct electric heating. Although the drop from 60,000 to 55,000 units between 2009 and 2013, the Swedish reversible heat pumps' market is very similar to the Spanish one; this is an important result helpful to affirm that the majority of such devices are going to be used also for space cooling during unusual hot summers. As concerns GSHP, Sweden was the largest European market in 2012, with around 24,502 units sold. Beside strict limitation for electric use in the residential sector, applications of ATW are concentrated in the Southern regions; nevertheless, ATW heat pumps have recorded a huge reduction in terms of sales (around -60%).

Regarding radiant panels, they have been very popular in the country, accounting for the 61% of the hydronic heating market. In particular, the progressive installations of condensing boilers and GSHP have led the radiant technology to gain a significant role against radiators. Therefore, taking all into account, split systems are more suitable for cooling purpose in apartments' block where district cooling is not so advanced but the same heating network cover the 82% of the total multi-unit building stock. Radiant cooling should become a relevant technology for single-family houses equipped with ATW and GSHP; the same should improve its position also for multi-family segment, since, as previously said, it is attracting many attentions from the heat pumps market.

[118] The share of GSHP and ATW in the global heat pumps' market was around 56% in 2012



Source: BSRIA

Figure 130 - Swedish Heating Scheme (Source: Radiators and UFH)

FINLAND

Finland is the second most important Scandinavian State for heat pumps because this product is recognized though the Country as a "promising technology to fulfil the national obligation and targets on the use of renewable energy"[119]. Renewable sources covered the 32.9% of the national energy mix in 2011. The existing buildings stock is formed by 1.19 million of single-family houses and 1.7 apartments. The Finnish GDP per capita is around € 30,000.

As previously stated, the Finnish market of domestic heat pumps is mature and currently this kind of product is preferred in new construction, as well as for retrofitting and replacement. The penetration of heat pumps is very high in the single-family category, in which over the 30% is equipped with the same. As in the Swedish contest, multifamily segment is evolving toward an expensive use of heat pumps for space air conditioning. While the global market is experiencing a reduction of sales due to saturation and precarious economic conditions, the number of installations in apartment blocks has increased of 30%. The Finnish scenario is quite similar to the Swedish one; air/air and GSHP are the privileged solutions, respectively with shares of 74% and 21%. While the former has recorded a descendant trend since some years, GSHP installations are rising, with more than 13,000 units sold in 2011. Ground heat pumps have increased their relative share in the Finnish heating scheme from 10% in 2000's to nearly 30% by 2008. Also in the Finnish scenario split and radiant cooling are expected to cover similar positions and to be dominant technologies; great sales of reversible ATA ensure that such devices can be used also for space cooling, as well as the spreading of GSHP and district cooling is going on putting radiant panels to be a privilege alternative.

[119] *JARN, August 25, 2012*

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	1819	1150	992	979	-46,18%
WTW				18	
GSHP	6137	8091	13941	12953	111,06%
ATA	57977	53821	55286	44956	-22,46%
Total	65933	63062	70219	58906	-10,66%

Table 37 – Finnish Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

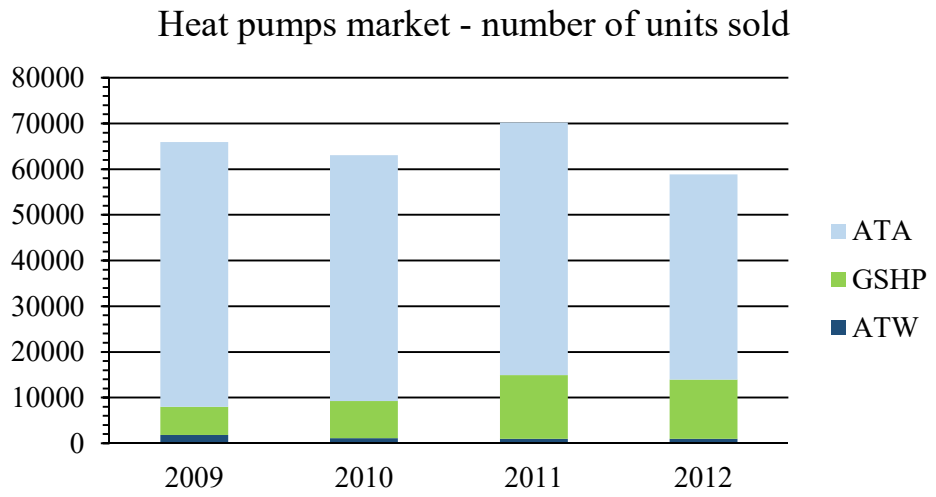


Figure 131 - Finnish Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

NORWAY

As the Finnish scenario, the Norwegian heating scheme is mainly based on electricity, due to low electric energy price[120]. This is the reason why the majority of dwellings are not equipped with hydronic heating distribution systems and air-to-air heat pumps are one of the most popular technology among the Country. According to *European Heat Pumps Market and Statistics*, heat pumps supply more than 30% of households. In particular, from the data below, in 2012 were sold 67,383 units, where the 90% were in the configuration air/air. In addition, the document just mentioned highlights the fact that in Norway there is still present a small market of heat pumps for ventilation and in the arrangement VRF.

Therefore, beside it is difficult to imagine and predict a significant cooling demand in Norway in the next few years if compared to other European ones, the dominant solution should be splits, given the current national space-heating scheme. The conversion toward

[120] The electricity price in 2013 was 0.06 €/kWh in Norway

hydronic heating distribution systems is not probable; otherwise, the same will be very slow due to the translation inertia.

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	4154	3530	2914	2806	-32,45%
WTW				18	
GSHP	3532	2863	3677	3211	-9,09%
ATA	75626	87222	76394	60959	-19,39%
Total	83312	93615	82985	66994	-19,59%

Table 38 - Norwegian Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

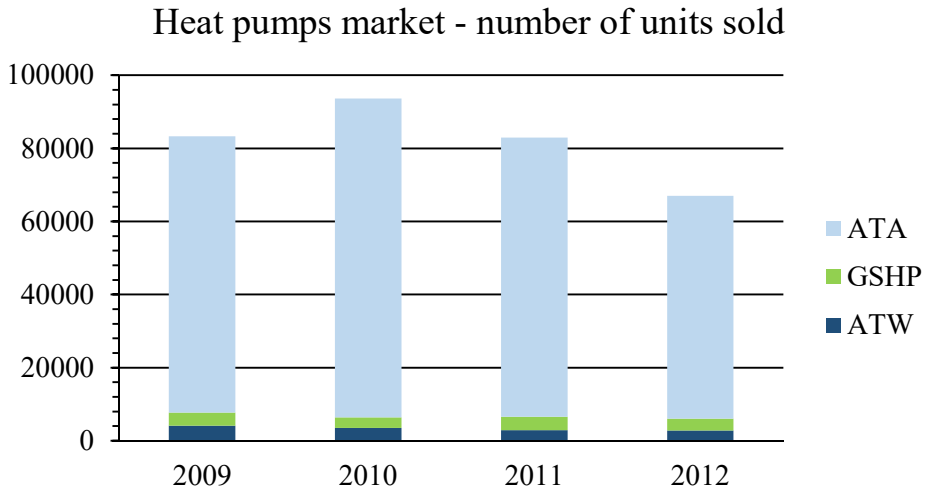


Figure 131 - Norwegian Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

DENMARK

There are 2,750,000 households and the 62% of the same are supplied with district heating, 15% are connected to the gas grid, while the 14% and 9% use respectively oil boilers and electricity as main source for space heating[121]. The Danish Government has adopted two important actions: a ban of installation of oil and gas-fired boilers in new residential edifices from 2013 and the installation of the same in existing building located in areas with district heating or gas-grids from 2016. This is emblematic in order to imagine the supposed potential of renewable sources/generators such as heat pumps. Denmark has be the fastest increasing European country in 2012 as concerns heat pumps market. In particular, ATW, ATA and exhaust air/air configurations have given the greater contributions with a growth rate over the threshold of 30%, between 2011 and 2012. Therefore, there is a strong increasing of air-base

[121] *Heat Pumps market and statistics report 2013*

heat pumps, as well as of the hydronic arrangements. Higher will be the role they will play for space heating, the greater the position they will have for summer air-conditioning. In the end, it is important to underline also the constant situation of ground source heat pumps.

Heat Pumps Type	2009	2010	2011	2012	2009/2012 evolution
ATW	1123	1325	1597	2113	88,16%
WTW					
GSHP	3475	4137	4172	3072	-11,60%
ATA	18450	11240	15513	21635	17,26%
Total	23048	16702	21282	26820	16,37%

Table 39 - Danish Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

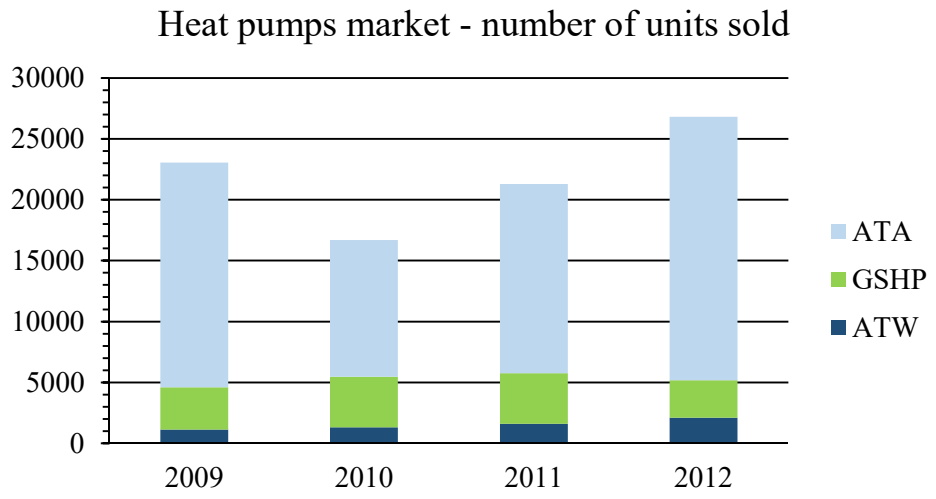


Figure 132 - Danish Heat Pumps Market (Source: European Heat Pumps Market and Statistics)

VII. Prognosis for the Future European Application Cooling, in Multi-Family Houses

In conclusion, the present analysis offers a forecast focusing on how the context of residential air conditioning can change in the next fifteen years. A detailed study of the past market and the available technologies makes it possible to draw up a projection, which can be as much truthful as possible. Specifically, the study has identified three areas of evolution: the expansion of the European residential cooling demand, the technological development and change of impacts on the market given by relevant system solutions.

Since the beginning of the new millennium, it has become commonplace to say that the European air conditioning demand is growing, even in the residential sector. Even if the market has been strongly affected by the international financial crisis in the years after 2009, nowadays the European context seems to recover, manifesting still dynamic and with great potential. As confirmed by *Rescue – EU District Cooling Market and Trends,* consumptions especially linked to domestic space cooling are supposed to increase by 2030. Although it is difficult to confirm estimations mentioned, prognosis developed by *Rescue* confirms results so far emerged. Most European Countries have achieved high rates of commercial penetration, while only Mediterranean States have been characterized by important developments also in the residential category. Accordingly, given its lesser maturity, the residential market will have more ample rooms of improvement in the next few years. In addition, Figure 133 shows that there are still gaps of expansions if one compares European markets with the most advance one in the residential cooling field, such as China, Japan and US.

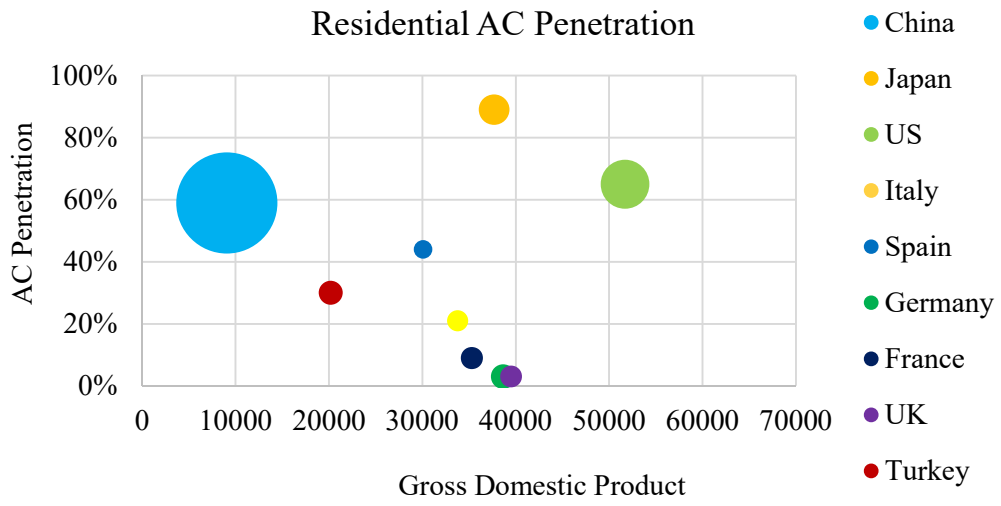


Figure 133 - European Residential Cooling Market Trend (Source: Rescue – EU District Cooling Market and Trends)

AC Penetration (2013)	Italy	Spain	Greece	France	UK	Germany	Turkey
Residential	21%	44%	48%	9%	3%	3%	30%
Commercial	44%	72%	55%	55%	42%	55%	42%

Table 40 – Air Conditioning Penetration (Source: JARN journals)

Beside the common denominator between the past and the future decades is to be identified in a continuous growth of domestic demand for cooling systems, the spotlights are slowly moving away from those Countries that have been protagonists of the European market up to now, and they are shining on other participants which are increasing their positions. In other words, in the next fifteen years, the residential cooling demand is supposed to increase especially in European Members that are becoming fundamental actors as Italy, Spain and Greece have been so far. The three mentioned Mediterranean Nations have recorded a sharp downturn caused by the economic crisis, which have led the same to reduce their markets strongly. Indeed, it is significant to observe that the decrease of split units sold was around -60% for Italy and Spain, and -50% for Greece, between 2004 and 2013. As previously stated, the cause is related to the heavy impact of the economic recession. However, the Mediterranean market is getting closer to a first phase of stagnation, due to already high residential penetrations; even if secondary, this can be identified as an additional motivation that has contributed to generate this negative trend.

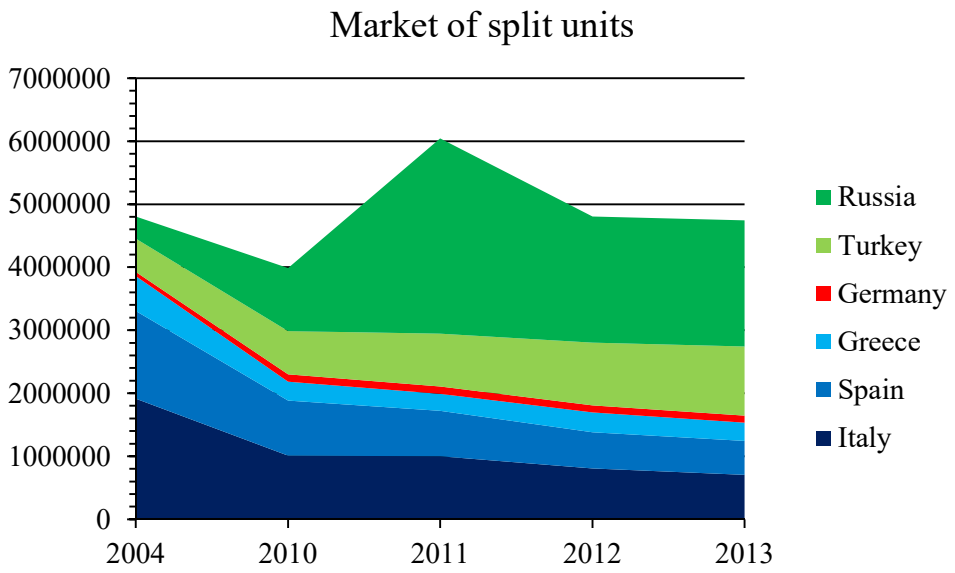


Figure 134 – Market of Split Units (Source: BSRIA and JARN)

Figure 134 shows how emerging Nations, such as Russia and Turkey, have compensated the decline experienced in South Europe. Since many years, Turkey has been

following a gradual growth driven by better national economic conditions, as well as by favourable climatic characteristics. The Russian case is quite singular and representative of a country in North-East Europe, which registered unusual hot summers like the one of 2010. Russians have begun a run toward air conditioners' procurement since 2011; JARN predicts that 3,800,000 split units will be sold in 2016. Nowadays, Russia is the fifth world air conditioning market. Turkish and Russian examples are helpful to make it clear that there will be other players in the next decade in addition to the Southern Europe Countries, which will maintain positions of prestige. Specifically, Central Europe, with Germany and France, East and South-East Europe are expected to play a dominant role in the evolution of the residential air conditioning demand.

Therefore, the following question is obvious: which are the factors that are moving the European market toward an expansion of the same?

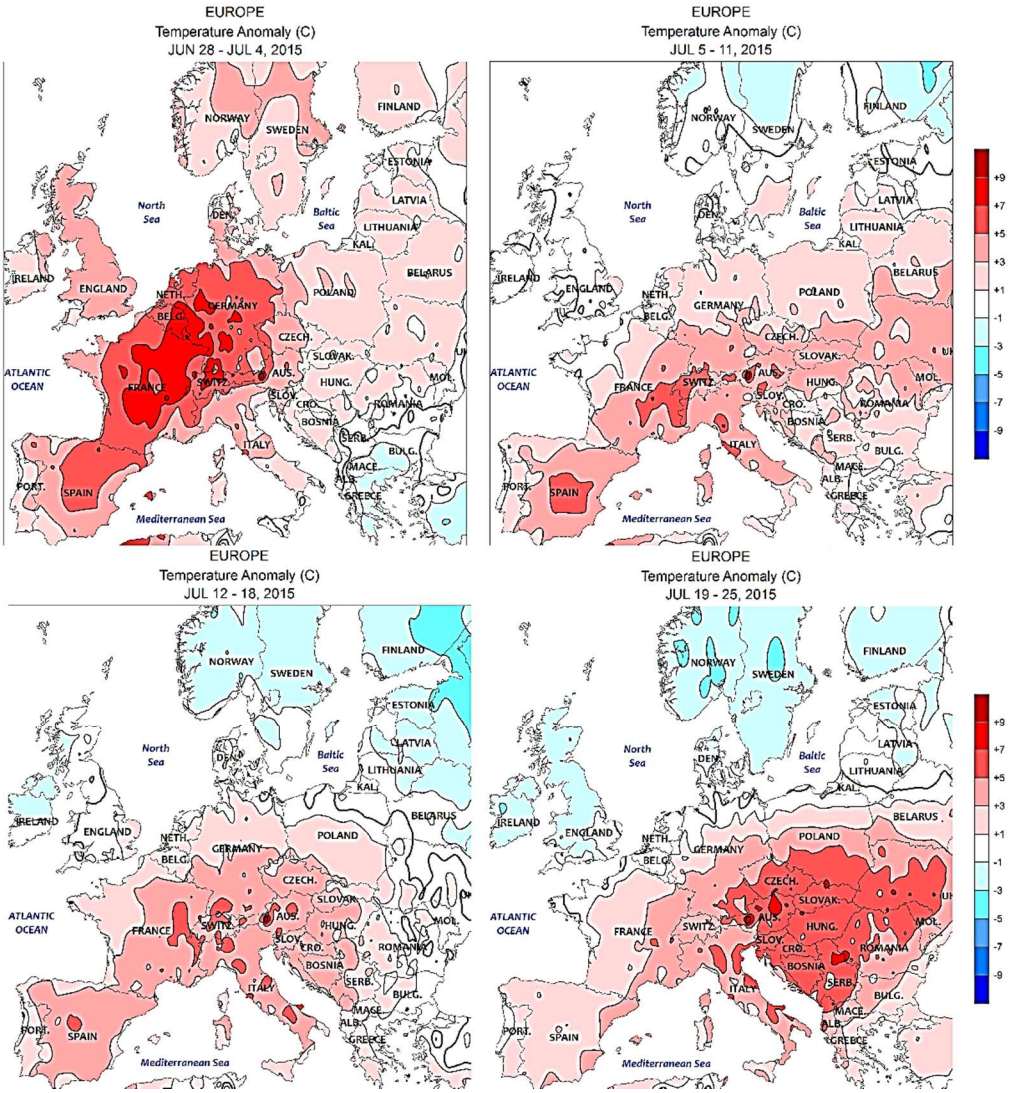


Figure 135 – Temperature Anomalies (Source: NWS-NOAA Europe Temperature Anomaly)

It is easy to imagine that everyone would answer by referring to climate changes as main driving factor. The climatic issue, as a matter of fact, is the core of domestic air-conditioning markets; thus, there is an inextricable link between demand and effective cooling necessity. This is the reason why the residential market has deeply developed with high rate of penetration in Mediterranean areas, where severe summer conditions of hot weather and high humidity have stimulated several Greek, Spanish, Italian and Turkish households to install cooling systems. The climatic factor will be the cause of sudden changes in mature markets, as well as it will trigger ones that are young or not yet completely structured. For instance, Russia increased split sales by 210% between 2010 and 2011 due to a torrid summer; temperatures did not go under 30°C for many days and at the same time the number of split units increased four times nearby Moscow. This significant result underlines climatic fluctuations as main driver of the residential cooling demand's expansion in the next decade.

Nowadays, many experts speak about a global warming as inspiration also of new potential scenarios. Hence, it can be successful to predict which European areas will experience greater climatic anomalies in the next future, since the same may lead to a substantial expansion of the cooling market and thus attract the attention of many sellers. Figure 135 shows the deviation of temperatures recorded in four weeks of July 2015 compared to average ones in previous decades. It is possible to point out that Central European Countries (France and Germany), Nations of Eastern Europe and many regions of Spain and Italy experienced an unusual heatwave in the last season. In addition, it is significant to consider that, in the ranking of the hottest years after 1800, 10 in the first fifteen belong to the new millennium[122]. As a result of weather anomalies, it is supposed that in the following years the above-mentioned areas will be prolific ones. This conclusion confirms the advent of new markets that will boost the residential cooling demand, as well as it demonstrates the prognosis according to which Eastern and Central Europe regions are expected to become key players in the European scenarios together with Mediterranean Countries.

Another fundamental factor concerns with the economic aspect, which has many influences on the residential cooling market and it can have many nuances. First, the economic analysis of the past decade has highlighted a deep connection between national trends and the financial status of the Countries. The capitals' availability that characterized Mediterranean areas at the beginning of the present millennium has developed profitable markets, such as Spain and Italy. Unlike what considered by some experts, better economic conditions may lead households to recognize needs so far unfulfilled rather than to create ones. As affirmed by

[122] CNR – consiglio nazionale delle ricerche

Ilkka Halava in Uponor's *Yearbook 2014*, "people's basic needs haven't changes over time, but the understanding of what it is possible has changed". Therefore, it is difficult to argue that domestic cooling is more a matter of luxury rather than a real need, especially in some European climates. On the contrary, it is more correct to emphasize that greater financial stability can increase comfort requirements and then turn on new markets, as well as addressing mature ones toward more advanced technologies that provide higher wellness. Indeed, this is another significant nuance of the economic factor; wealthier environment can influence the success of various cooling systems. In particular, the attention toward lower investments will be prevalent over long-term savings due to lower operation costs also in the next fifteen years.

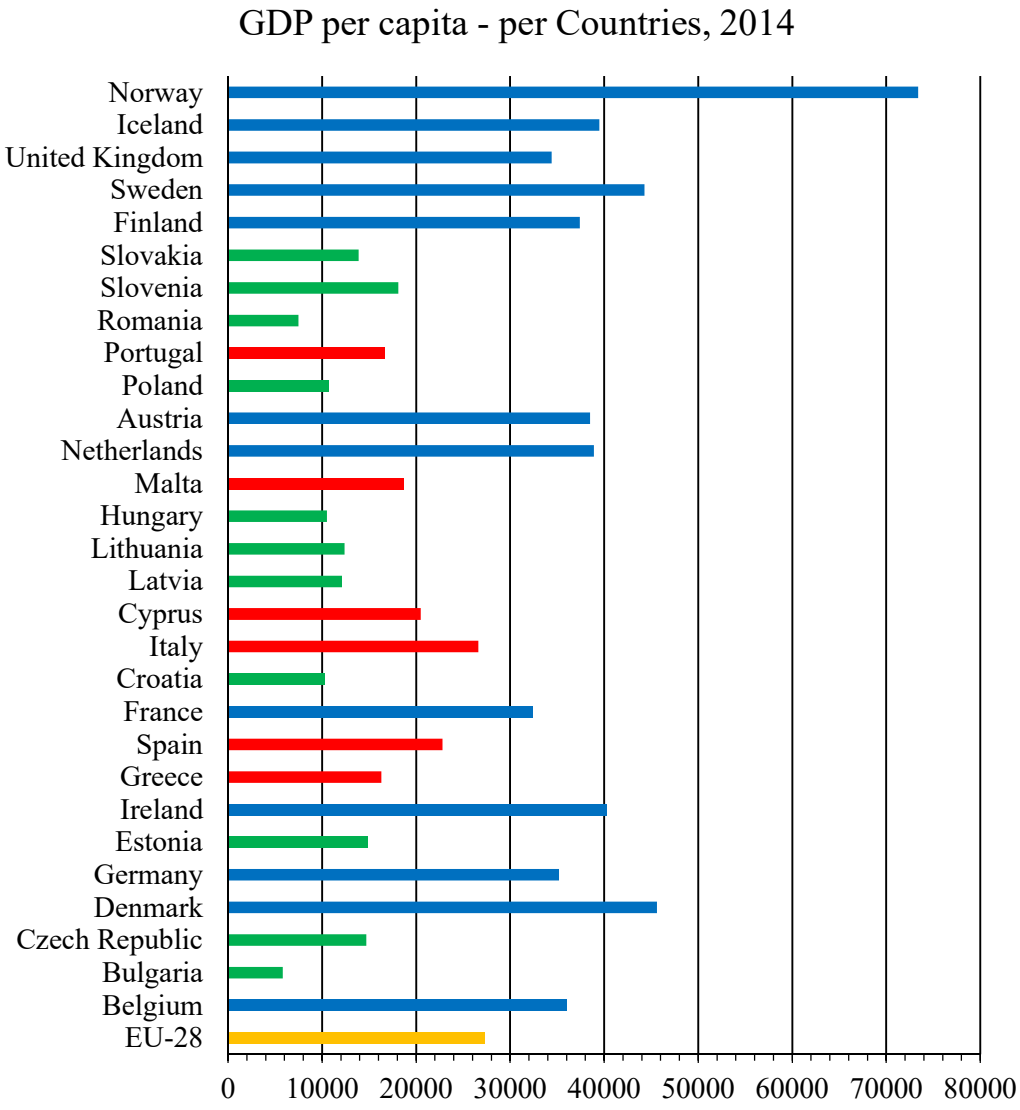


Figure 136 – GDP per capita, 2014 (Source: Eurostat)

Eurostat data about unemployment rates and gross domestic products reveal significant results on European areas considered so far. The first conclusion shows that all Mediterranean Counties are described by GDP's values below the European average; moreover, high levels of unemployment (over 20% for Spain and Greece, just below 15% for Italy) prove heavy impact due to financial crisis. Therefore, Mediterranean Nations will undertake a difficult and slow process of economic recovery, which will be a panacea also for cooling markets of the same regions. On the other side, Eastern and Central Europe Countries are united by relatively low unemployment rates, ranging between 10% and 5%, hence below the European average. However, a strong discrepancy emerges when considering the availability of households' assets; while Central and North Europe are among the richest Nations, the lowest economic capital cities characterize Eastern regions. This financial polarity will have many implications on the areas that are supposed to evolve the European cooling demand. Specifically, these influences will reveal markets otherwise profitable and different successes of cooling systems. Devices that may satisfy purely economic requisites will likely experience great progress in Eastern Europe, while more advanced solutions, and hence more expensive, are supposed to play a more important role in the regions of Nord and Central Europe.

The third factor to be considered deals with residential construction industry; in particular, the present analysis pays great attentions to the segment of multi-unit buildings. Such sector is very important among the European building stock, covering the 36% of the total area used for residential purposes. Significant contributions are recorded in Mediterranean Countries, where apartments describe about 70% of total Spanish, Italian and Turkish dwellings; similar values are recognized when considering the role of condominiums in the total residential floor area. This result is fundamental in order to give correct interpretations about the historical development of Mediterranean cooling markets, as well as to imagine probable evolutions of the same. For instance, the dominant multi-family component in the geographic areas into account has had deep influences on the success of some cooling devices, such as split air conditioners, which are able to meet the requirements of size, installation, use and price. Indeed, it is known that a large part of households rent apartments[123], as confirmation that the financial availability of the same is lower than the one of families living in single-family houses. Households' economic status has strong impacts on

[123] *Entranze* affirms that the share of renting families is 32% in Italy, 15% in Spain, 80% in Germany and 40% in France

the success of some cooling systems, as well as on manufactures' choices when considering a plant for summer air-conditioning already in the design phase.

On the other side, Countries in Central and Northern Europe are characterized by a lower presence of the multi-family component; the average penetration of the same on the total residential floor area is around 30%-40%. UK and Norway are singular cases, since the single-family segment is hugely predominant.

The position of multi-unit edifices is further emphasized by data provided by *CIC*, which shows that in Europe this category recorded the best performances in the review period 2008-2013 and the same is expected to develop more quickly between 2013 and 2018. This result confirms the world trend observed toward urbanization; according to Uponor *Yearbook 2014*, nowadays half of the world's population live in cities and ¾ of the same is supposed to be urban by 2050. Therefore, the greater will be the flow of households who will move to urban centres, the more significant the role of multi-family habitations. Focusing on Europe, Italy, France, UK and Germany are supposed to give more outputs in the field of condominiums. Figure 137 shows data about CAGRs in the reviewed periods 2008-2013 and 2013-2018, and bubbles indicate sizes assumed in 2018-2019 in terms of value (EUR Million) of the selected Countries.

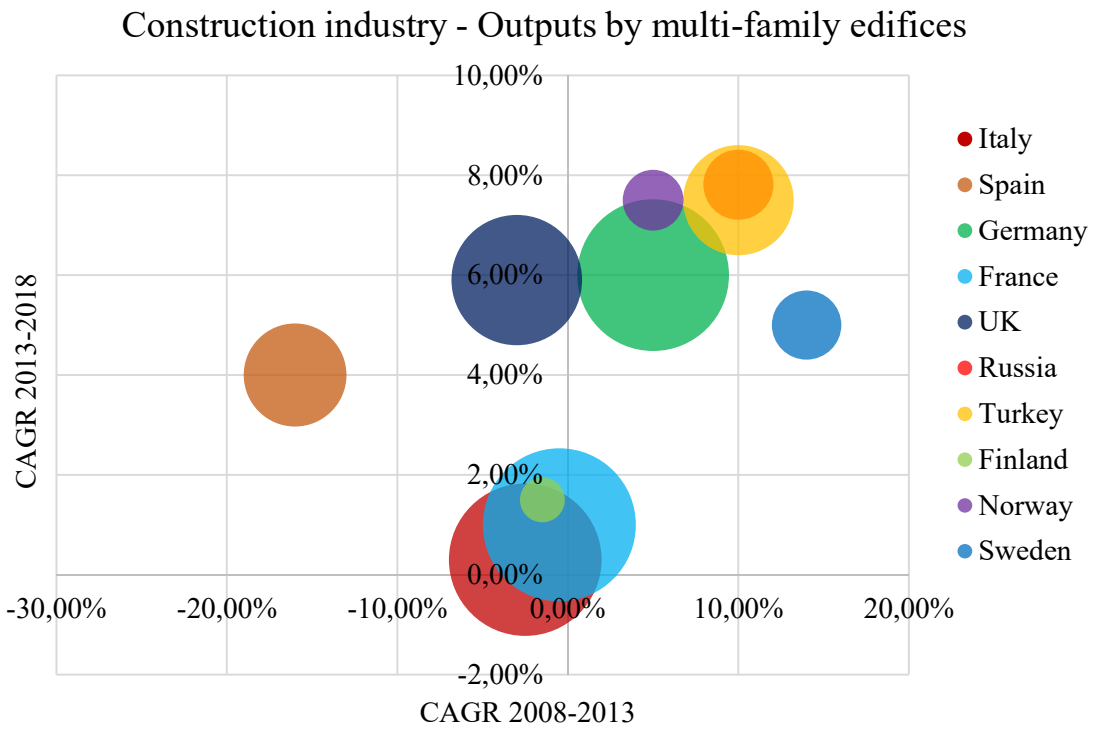


Figure 137 – Outputs by multi-family edifices (Source: Construction Intelligence Centre)

Outputs Multi-family Construction industry	Italy	Spain	Germany	France	UK	Russia	Turkey	Finland	Norway	Sweden
EUR Million 2015	60.915	23.111	53.059	60.580	37.147	10.609	26.579	5.134	7.784	11.454
EUR Million 2018	63.961	29.139	63.213	64.316	46.794	13.516	33.411	5.497	10.154	13.263

Table 41 Outputs by multi-family edifices (Source: Construction Intelligence Centre)

Million €	Residential Outputs	Italy	Spain	Germany	France	UK	Russia	Turkey
2015	New Construction	47.124	35.958	46.410	88.267	43.672	22.934	19.115
	Refurbishment	66.208	12.563	77.162	25.078	34.056	4.595	8.092
2018	New Construction	49.354	43.930	53.793	92.232	53.585	28.306	24.034
	Refurbishment	71.219	15.941	91.278	26.754	43.038	5.659	10.148
	NC evolution	4,73%	22,17%	15,91%	4,49%	22,70%	23,43%	25,73%
	REF evolution	7,57%	26,89%	18,29%	6,69%	26,37%	23,14%	25,40%
	REF share 2015	58,42%	25,89%	62,44%	22,13%	43,81%	16,69%	29,74%
	REF share 2018	59,07%	26,63%	62,92%	22,49%	44,54%	16,66%	29,69%

Table 42 – Residential Construction Outputs (Source: Construction Intelligence Centre)

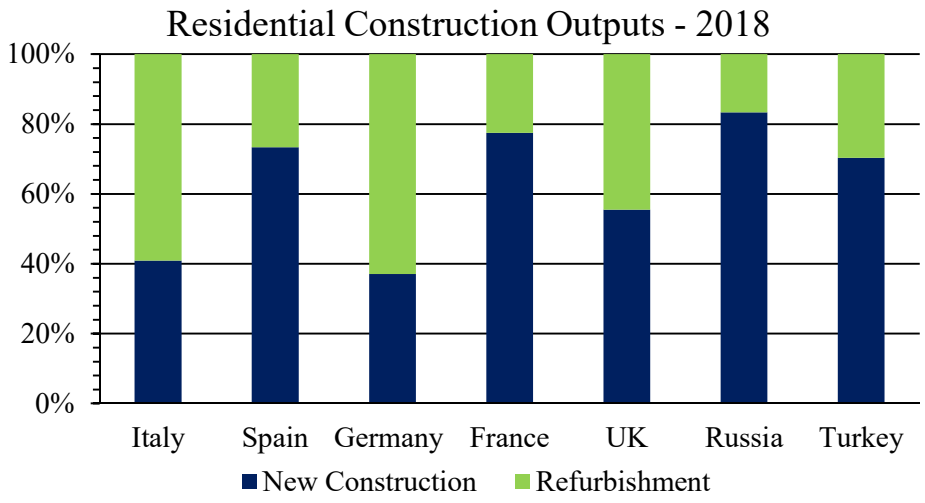


Figure 138 – Residential Construction Outputs (Source: Construction Intelligent Centre)

According to *CIC*'s forecasts, Germany and England might expand considerably in the segment of multi-family houses, reaching outputs similar to those of France and Italy, which, on the contrary, will record only weak improvements. Even Spain and Turkey are significant scenarios, since they are supposed to grow respectively by +4% and +7.5%. It is important to consider that outputs of multi-family category take into account all types of activities, namely the contributions of new constructions, as well as refurbishments and maintenances. Table 33 shows *CIC*'s data of the global residential sector split by activities. It emerges that the trend is leading refurbishments and maintenances to become the most fruitful segments, especially in Italy, Germany and in the UK, the buildings stock of which is strongly represented by edifices built between the end of the Second World War and the 90's. Now, in

Spain, France and Turkey, the new constructions' component is expected to remain predominant. However, in general, "in developing countries, new buildings will be the focus, with anticipated growing demands for air conditioning, reinforced by increasing living standards and climate change"[124].

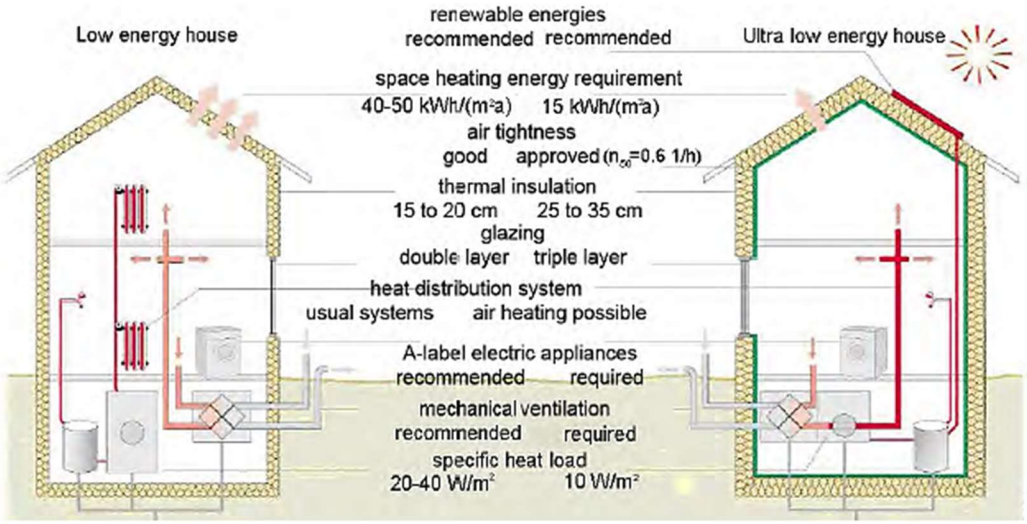
Inside the building factor, a driving force for a significant reduction in residential energy consumptions and CO_2 emissions is represented by the spread of nZEBs. European directives EPBD 2010/31/EU and RES 2009/28/CE, indeed, are urging EU Members to draw up a roadmap to make the residential sector more energy efficient by 2050, the former by promoting the diffusion of low-energy buildings and the latter by supporting the use of renewable sources. Specifically, by 2020 all new domestic constructions must be categorized as nZEB. The same trend that is leading to the spread of low energy buildings is at the same time emphasizing the attention to ventilation and cooling systems. As a matter of fact, in such houses thermal loads change significantly, in particular space heating needs are notably reduced and the share of DHW increases. Moreover, mechanical ventilation is in most cases required to guarantee air exchange due to air-tight building construction, while the integration of comfort cooling options is increasing, specifically in hot and humid climates. Nowadays, there is not a clear and unambiguous definition of nZEBs and, hence, it is difficult to describe real performances of the same. Even though principle calculation methods are similar and based on EU standards, idea on nZEB may differ[125].

Nevertheless, the most commonly accepted definition is the one of a building that annually produces as much energy as is measured on site; moreover, it is necessary to underline that the energy required is provided by renewable sources and therefore such houses are combustion free and strongly electrified. In other words, the thermal energy for both space heating and DHW does not come from combustion.
High performances of nZEBs are ensured by:

[124] *IEA – The role of heat pumps in nZEB*
[125] For instance:

- *Austria*: specific heat load lower than 40 W/m^2 and space heating energy need in the range of 50 kWh/m^{2}y;
- *Switzerland*: typical heat load of 20 W/m^2 and weighted delivered energy of 38 kWh/m^{2}y;
- *Norway*: heat load of 30-40 W/m^2 and space heating energy need less than 58 kWh/m^{2}y;
- *Netherlands*: energy need of 15 kWh/m^{2}y;

- The use of high performance envelop and windows, as well as the application of hot water distribution system in order to minimize energy loads;
- The use of maximum efficiency systems to meet loads with minimum energy use;
- The use of systems' operation strategies employing advanced controls, in order to optimize the operation of the same during the entire service life;



Comparison of typical values for low- (left) and ultra-low energy houses (right) for the (modified of MINERGIE®)

Figure 139 – Low and Ultra-Low Houses (Source: Umbrella Report, IEA, Annex 32)

Together with considerations on systems' management and envelop, nZEBs provide an optimal interaction with the solar source. On the one side, the installation of PVs and thermal solar collectors allows producing green electrical and thermal power. The considerable drop of the heating demand leads to decrease solar thermal panels' size and their costs. On the other side, layout and orientation are designed to exploit solar contributions for both free heating and lighting during winter season; this is possible by projecting large glazing surfaces, especially in the south façade. On the contrary, the design of shading devices and the insulation of the building's structure, allows the user to exploit sunlight without the same contributes as overheating internal rooms in summer. However, the necessity to face up with internal loads remains, due to the increasing penetration of devices and appliances. Together with climatic aspects, this is another reason why shading systems are not enough to replace cooling plants in warmer European areas. Nonetheless, as confirmed by Ilari Aho, Uponor vice president, in

the next fifteen years households are expected to desire summer air-conditioning equipment even in scenarios where they are not effectively needed[126].

Hence, what will be the impact of nZEBs in the context of summer air conditioning? The main consequence that the present study has identified concerns a gradual change in cooling demand features, which is supposed to become similar to the heating request or even larger. Furthermore, it is also supposed that the same may expand in terms of time and become less fluctuating but broadly stable throughout the days. Therefore, cooling systems might not be perceived as simple appliances anymore, rather they are expected to cover a significant position equal to the one that has been for heating plants so far. This result is going to influence the technological and configuration evolution of cooling systems.

On the other side, considering specifics of the cooling demand that describes existing apartments' stock, these are expected to remain linked to principles of low response time and possibility to individual control also in the next decades. Summer air-conditioning requirements are very changeable and, in addition, subjective. This implies that systems must be able to satisfy requisites of occupants in a short time, when they are activated by a person or by automatic control. Another key aspect is that many households prefer to limit the installation of cooling equipment just in some rooms of the house, as the sleeping area; this is due to the fact that people spend less time at home, limiting their presence only in the evening. Furthermore, installing just one compact element in order to cool several rooms provides significant cost saving.

Summarizing what stated above, the following conclusions emerge for the next decade of multi-family systems, in both new and existing buildings.

1) In case of nZEBs or at least modern buildings, mechanical ventilation is supposed to be always present. Hence, exhaust air could be used as a heat source for fresh air, working fluids or for DHW. The same might be used also for dissipate internal loads in the outdoor environment;

[126] For instance, nowadays, cars without air conditioning are not sold even in Scandinavian regions

2) Systems must be able to meet less heating capacities, as well as to fulfil increasing cooling demands. This could have significant influences on sizes of both distributions systems and generators[127];

3) The plant must be reversible: the same distribution system, as well as emitters and generator, must be suitable for providing both heating and cooling;

4) In apartment block, a trend towards centralized systems has been recorded. This leads to less investment costs and higher performances;

5) The system must have multiple integrated functions. In particular, it has to ensure fresh air ventilation, as well as humidification/dehumidification of the same. In some climatic zones, the cooling system has to guarantee a latent load control even if it is installed in existing buildings. There is also a trend towards equipment compatible to interact with photovoltaic and/or solar thermal panels. In the end, also the production of DHW could be integrated in the plant's configuration.

6) The system has to follow faithfully the thermal load's trend during the day required by indoor environments. This often coincides with the adoption of inverter and other devices or management/control solutions, which can adjust temporally and quickly the output power of the plant in relation to the thermal load effectively required. The result is identifiable in lower energy consumptions.

The idea of a centralized and reversible system materializes into a trend recorded in Europe toward the adoption of reversible heat pumps as future generators and replacement of traditional combustion boilers. This is the most evident technological change that is supposed to be recognizable in the next fifteen years, also in the context of low-energy houses and apartment buildings. A reversible heat pump eliminates the need of both boiler and chiller, and the same will give the opportunity to install a single plant made by generator, distribution systems and emitters, suitable to operate both in summer and in winter. The growing penetration of such devices will also affect the success of some emitters. In other words, in the next decade, it is probable that the role of some final elements might not depend on their

[127] Many manufactures are developing some prototypes (heat pumps) adaptable to typical range of low-energy houses of 3-5 kW

technological improvement so much as the advent of reversible heat pumps should influence the same. The latter, as previously anticipated, satisfies prerequisites of a reversible and centralized generator and, therefore, they are suitable for multi-family applications. Furthermore, since the majority of these devices is electrically driven, they ensure a perfect interaction with PVs in order to produce space heating and cooling in a total renewable way. On the other side, there are also some heat pumps thermally driven by natural-gas combustion; nonetheless, the present study considers such technology not compatible with gospels of next decades since it represent a technological improvement in the wrong direction. Confirming this forecast, the market analysis (Figure 140) has shown that heat pumps have not experienced great success in the segment of multi-unit blocks, but it is attracting significant attentions in the last few years. The Scandinavian scenario is a clean example, since installation of heat pumps is increasing considerably from year to year.

	New building	Renovation
Residential: single/double family house	Mass market currently developing.	Increasingly recognized market (France, Germany, Sweden, Switzerland), importance of domestic hot water units increasing.
Residential: Multi-family residency	Small; market developing.	Small, market developing.

Figure 140 – Residential Penetration of Heat Pump (Source: Heat Pump Market and Statistics)

Nowadays, when speaking about centralized plant for both heating and cooling in the residential sector, it usually means hydronic systems. Therefore, air-to-water and ground-source heat pumps have to be considered. Both configurations well match with low temperature emitters (or high temperature in cooling mode), as this combination provides better performances for the generator. In case of new multi-unit buildings, GSHPs occupy the underground boiler room and, therefore, it guarantees total availability of the roof for installing PV collectors and/or thermal solar panels. GSHPs can gain many benefits from new low-energy edifices, because a drop of annual loads corresponds to a reduction of the probes' length; so there are both economic and of installation advantages. On the contrary, ATW heat pumps are usually applied on the roof and are characterized by lower installation costs. They are suitable to be applied in both new and existing users.

Even ATA heat pumps, or generically speaking split systems, are evolving in order to meet requirements of reversibility and centrality for multi-family houses. The technology is developing towards multi-split and VRF configurations, where many internal units can be connected to just one external element or "generator". Most of the products have been sold in so-called heat pump arrangement, that is to say they are reversible. Nevertheless, only the

9%[128] (or even less) of the latter part is effectively used with the main function of heating in Italy and Spain. These coincide with the amount of splits sold in Scandinavian regions, which are mainly used in winter to support other heating systems.

Therefore, it is clear that there is a strong historical imprint in the European scenario that leads hydronic systems to prevail for heating and splits for cooling. Nevertheless, there is still the doubt of which of the two systems will be the dominant reversible solution in the market, especially considering both segments of existing and new apartment buildings.

- *EXISTING BUILDINGS:*

  When speaking about the installation of an air-conditioning system in an existing multi-unit building many variables emerge, but the most important one concerns with the fact that the plant has to deal with distinct users. The system may be required by all households, as well as by only some of them; the choice varies because of this. Therefore, it is supposed to consider an inhabited apartment block, whose users have a hydronic heating systems made by radiators and gas boiler, since this is the most widespread solution throughout Europe. From the analysis made, it emerges that the economic factor and the one inherent with the installation procedure are the most considered in case of existing multi-family buildings. Households prefer a cheap system, easy and quick to install, with a low aesthetic and dimensional impact on the existing structure. Hence, the present study has selected FCUs and splits as possible solutions.
  Floor standing fan coils are an excellent aesthetic and dimensional substitute of traditional radiators. The formers, therefore, can replace the latter and they can use the same hydronic distribution plant and, in addition, ensure a double operation for heating and cooling. This is possible by adding a chiller or by replacing the old boiler with a new reversible heat pump. However, in both cases it is necessary to find an outdoor place where install the generator; the roof is usually privileged. Although the work for the new configuration is quite complicated, the replacement of radiators for new FCUs does not bother households. From the economic point of view, one should consider that one internal emitter costs around 300-400€, while a 20 kW hydronic heat pump's

[128] *Heat Pumps Market and Statistics, Report 2013*

price is around 8000-9000€. Therefore, considering a ten-apartment' block, the components' cost for each family should be around 3000€.

Another solution is the installation of a split system, especially in the configuration multi-type and VRF. The option to install one or two single-splits per dwellings is not ignored given the extraordinary cheapness of the solution; it is possible to purchase two devices with a minimum cost around 2000€. Nevertheless, it is fundamental to consider the huge aesthetic impact on the building's structure because of several outdoor condensing units. On the other side, multi-split arrangement allows powering at least ten internal units, which are probably enough to satisfy requirements of five families if we consider that each of them should install a conditioner for both living and sleeping area. Therefore, with two outdoor condenser of 10 kW (4500€ each) and twenty internal emitters (500€ each), the investment results as the most convenient with 1900€ per household. However, it is clear the lower aesthetic impact of just two external units. VRF is another alternative as centralized cooling plant. VRFs' installation is quite complicated especially for the refrigerant circuit, but they are suitable for easy changes, such as the addition of new internal units. As far as components' costs are concerned, prices of internal units range between 400-1000€, while the ones for the external element are around 5000-7000€. Therefore, theoretically each family might pay over 2000€.

Figure 141 – Fan Coil Unit and Split Internal Unit (Source: Climaveneta and Daikin)

There might be a third solution, which consists in the installation of underfloor radiant panels for both heating and cooling, with a reversible heat pump as substitution of the old boiler. Nevertheless, this is more expensive considering a cost of 80€/m^2 for panels and 8000-9000€ for a 20 kW hydronic generator.

In addition, the installation procedure considerably affects the households, since they must be away from home for a long period, as well as all the furniture has to be moved.

- *NEW BUILDINGS*

  The plant's choice in new apartment's blocks is not strongly influenced by installation's principles, as previously emerged for existing buildings. The factor that, on the contrary, has the greatest impact on new multi-unit edifices concerns with economic aspects, in terms of both investments and operating costs. Unlike what happens with single-family houses, in most cases households buy/rent a pre-built flat, whose structural, aesthetic and technical features have been established by the construction company during design phase. The latter, specifically, wants to guarantee apartments that combine quality and cheapness, in order to make the same attractive and affordable. The heating system has huge influences both on investment costs and dwelling quality; the same has to ensure good comfort during operating seasons, while its operating costs have to be low. Focusing on the scope within the present study, nowadays the majority of new constructions do not include a cooling system in the original project. This is also true in areas where the cooling demand is considerable, as in Mediterranean Countries. As a consequence, many households are used to install their own cooling equipment a few years after the purchase of the property. However, assuming a summer conditioning plant already included in the design phase of the buildings, which technologies could be installed? Besides geographic and climatic differences, it is important to consider that radiators and radiant panels are currently the privileged heating emitters for the European model of apartments block. Specifically, an increasing trend of radiant technology to detriment of traditional ones has emerged from the economic analysis; the radiant solution is improving its position also in multi-type category, thanks to a contemporaneous success of reversible hydronic heat pumps in the same sector. These are leading fan coils to cover a more significant position too. However, it is clear that split systems are going to be preferential cooling solutions where radiators are expected to be installed as heating emitters. Mini-splits are supposed to be installed also in dwellings equipped with underfloor heating panels; nevertheless, the number of radiant panels operating for both heating and cooling purposes is

expected to grow up considerably in the next decade, especially in climatic areas where summer humidity levels are not so excessive. As mentioned before, fan coils units are supposed to experience great success as reversible emitters, beneficing the increasing penetration of reversible electrically driven generators.

Table 34 shows a forecast of different cooling emitters' penetrations in the next decade scenario, and the same highlights that radiant technology should at least reach a share of 20% in the European domestic cooling scenario.

New Multi-Family Houses Heating and Cooling Scheme for next decades

Heating Emitters	*% Heating*	*Cooling Emitters*	*% Heating*	*% Cooling*
FCUs or Radiators	70%	FCUs or Splits	100%	70%
Radiant Panels	30%	Radiant Panels	60%	18%
		Splits	40%	12%

Table 43 – New Multi-Family Heating and Cooling Scheme for the next decade

Taking all this into account, the success of different cooling technologies is closely linked to principles of cheapness and compatibility with European climatic characteristics. Currently, mini-split systems summarize themselves economic benefits and adaptability to both hottest European climates, which are especially described by high humidity during summers, and any buildings structures. The interception of all these advantages will bring split technology to be the dominant cooling solution also in the coming years in Mediterranean Countries and South-East European zones. According to the present study, FCUs might benefit from good reputation in the same regions, while the radiant equipment is supposed to remain a much more secondary technology because of high investment costs, as well as more system complexity in order to face up with high humidity levels during summer. The latter, on the contrary, could record a remarkable success especially in Northern Italy, as well as in France and Germany, where for some years a positive trend towards hydronic heat pumps has emerged; such generators should trigger the market of some hydronic cooling emitters, especially radiant panels. Indeed, these geographical areas represent a prolific background where a wealthier middle class can support the diffusion of most advanced cooling equipment and where climatic features favour it. On the contrary, the necessity to face up with rigid winters and severe heatwaves will inspire the market of FCUs and split devices, which are expected to become dominant final elements for cooling purpose in Eastern Europe. Both fan coil and split devices satisfy requirements of instantaneous and individual control, as well as cheapness.

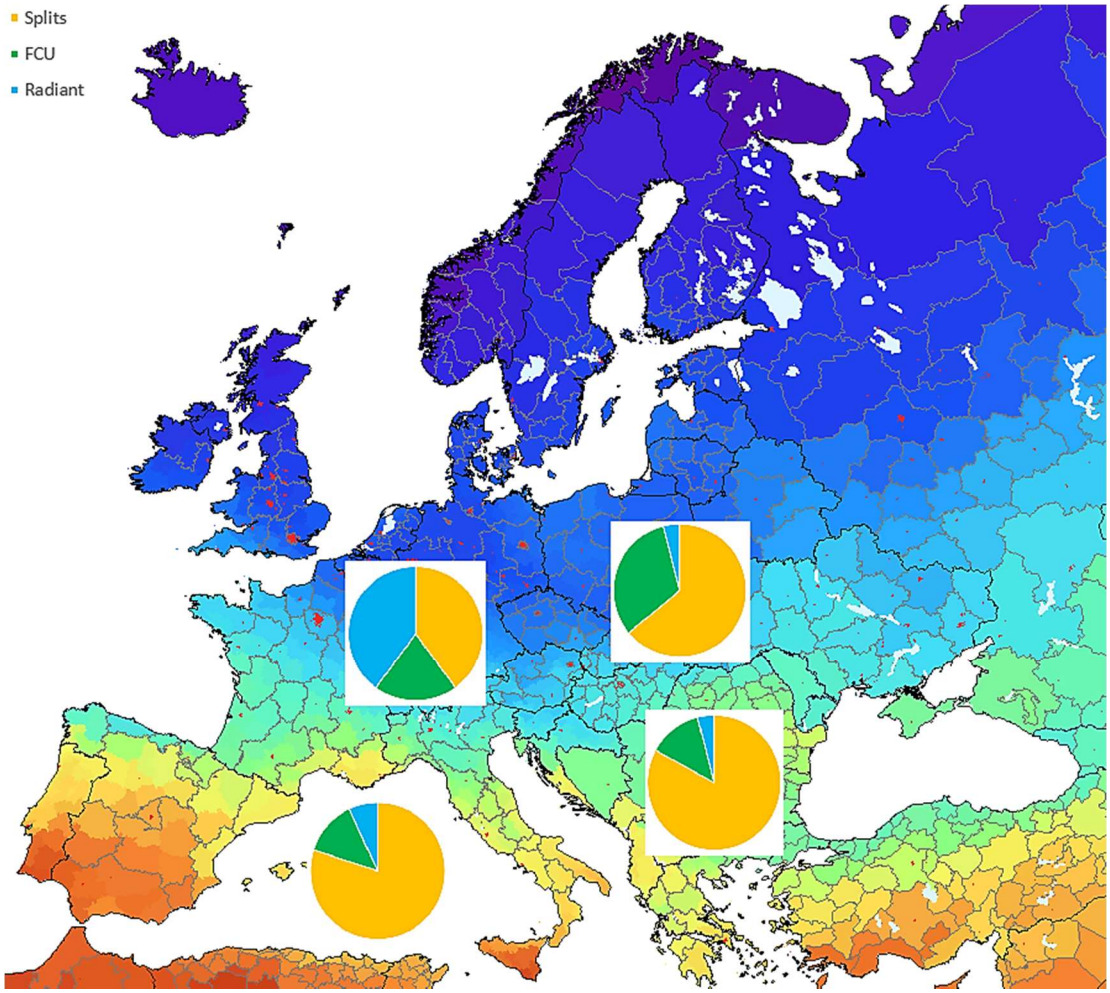


Figure 142 – Cooling Emitters Forecast Penetration in Europe by Typology

VIII. Italian Multi-Family Case: Design of a Domestic Heating and Cooling System.

The present chapter shows an example of a sizing and design of a domestic thermal plant in an Italian multi-family building. The building selected is located in Padua and it has been subjected to a restoration action, which involves the lining of the entire edifice with an insulated coat, the creating of a new top floor with insulated roof and the installation/design of a new air conditioning system for heating and cooling. Particular attention has been paid to the second and third floors since they have been subjected to major alterations and refurbishment works. Therefore, in order to have a better overview on the multi-family building chosen, it was decided to report the main views in terms of plants and façade.

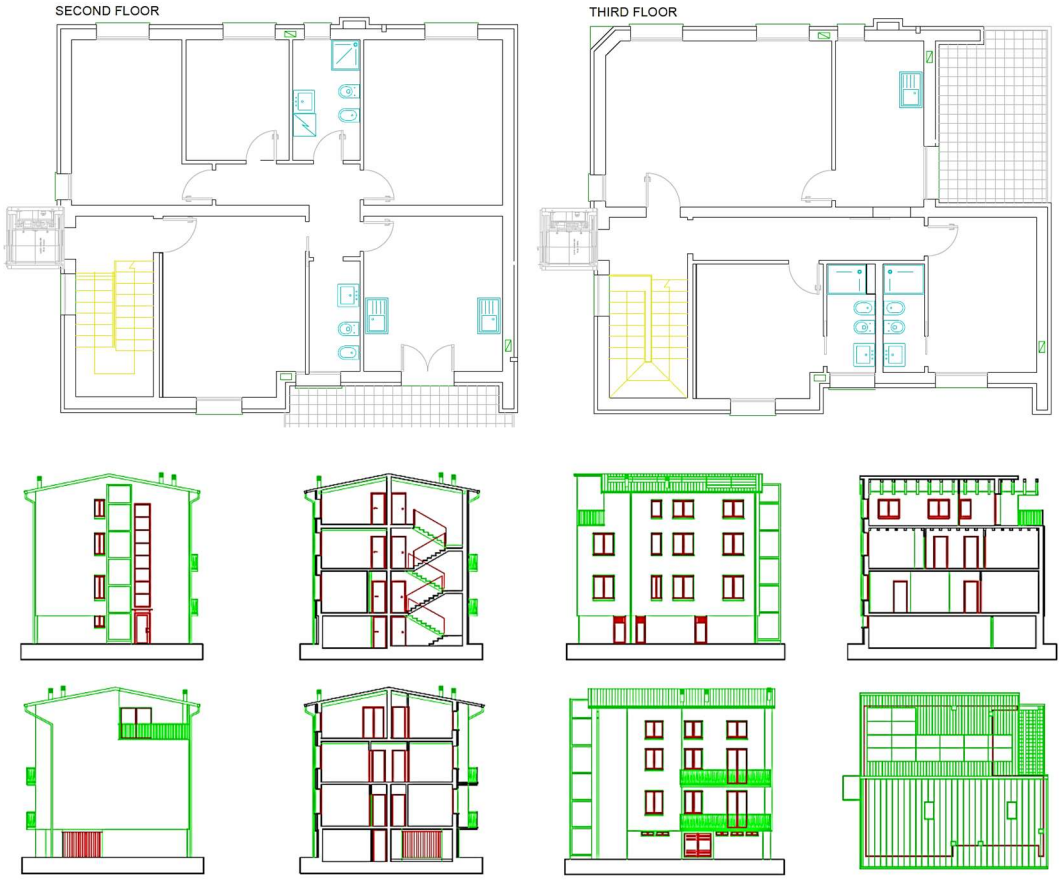


Figure 143 – Main views of the multi-family building selected in Padua

As previously stated, in order to improve the thermal performances of the building, it was decided to intervene on the structure by applying a layer of thermal insulation on all

external walls and on the roof. In addition, new and high-thermal performing window fixtures replaced the old one. The following tables describe the new stratigraphy and report the coefficients of thermal dispersion that characterized all the other structural elements. A fundamental aspect of the decision-making has been to design the insulation in order to comply with the national regulatory limits in terms of thermal transmittance; it is expected that the latter would be lower than 0.27 W/m^{2}K for exterior masonries and lower than 0.25 W/m^{2}K for roofs.

EXTERNAL WALL WITH INSULATION		
Materials	s (m)	λ (W/m K)
plaster	0,015	0,9
brick	0,25	0,276
plaster	0,015	0,9
ISOVER CLIMA 34-G3	0,1	0,034
plaster	0,005	0,3
TOTAL	0,385	
Theoretic Transmittance	0,257	W/m2 K
Adopted Transmittance	0,257	W/m2 K
National Regulatory Limit	0,27	W/m2 K

Table 45 – External Wall with Insulation

ROOF		
Materials	s (m)	λ (W/m K)
tavolato	0,022	0,15
vapour barrier		
rock wool ISOVER	0,16	0,037
breathable membrane USB		
TOTAL	0,182	
Theoretic Transmittance	0,223664	W/m2 K
Adopted Transmittance	0,223664	W/m2 K
National Regulatory Limit	0,25	W/m2 K

Table 46 - Roof

K wall	1,06	W/m2K
K internal wall	2,14	W/m2K
K window	1,60	W/m2K
K floor	1,40	W/m2K

Table 47 – Thermal Transmittances

Once set the renovation characteristics for the constructive part of the palace, the design phase proceeded with the thermal analysis of the same building by calculating the

maximum heat loss during winter and the maximum cooling need during summer. The knowledge of the powers just mentioned will be indispensable for the next phase, that is to say the dimensioning and design of the thermal plant. However, it is necessary to fix the boundary climatic conditions in order to evaluate what needed; specifically, the reference ambient temperatures for the city of Padua are respectively -5°C in winter and 32.5°C in summer. On the other side, the desired household conditions are of 20°C for cold months and 26°C (50% of relative humidity) for warm ones. Going into details, maximum winter losses of the buildings are considered as sum of two contributions, the first due to heat losses through walls and the second due to ventilation.

$$q_{tot} = q_{hea\ \ losses} + q_{ventilation}$$

$$q_{heat\ losses} = q_{walls} + q_{windows} + q_{increases\ due\ to\ orientation}$$

$$q_{walls} = K_{walls} * A * (T_{internal} - T_{external})$$

$$q_{windows} = K_{windows} * A * (T_{internal} - T_{external})$$

$$^{129}q_{ventilation} = n * V * \rho * c_p * (T_{internal} - T_{external})$$

SECOND FLOOR	qd	qv	qtot' (W)	qtot[130]
Kitchen	420,40	181,43	601,83	801,04
Bathroom1	115,35	68,47	183,82	244,66
Bedroom1	433,58	193,18	626,77	834,23
Studio	193,00	104,60	297,60	396,10
Bedroom2	416,71	153,50	570,21	758,95
Corridor	42,96	60,42	103,38	137,60
Bathroom2	94,41	46,54	140,94	187,60
Living room	514,77	224,01	738,77	983,31
TOTAL				**4343,47**

THIRD FLOOR	qd	qv	qtot' (W)	qtot
Bedroom1	353,83	151,80	505,63	672,99
Bathroom1	38,89	37,41	76,30	101,56
Kitchen	362,75	108,16	470,91	626,78
Living room	1335,36	314,83	1650,20	2196,41
Ingresso	295,71	83,95	379,66	505,33
Bathroom2	217,62	44,04	261,66	348,27
Bedroom2	671,68	147,99	819,67	1090,98
TOTAL				**5542,32**

Table 48 – Heat Demand

In addition, the determination of the maximum cooling need comes from the knowledge of two fundamental components of sensible and latent heat that it is necessary to

[129] n = number of air change per hour; V = volume

[130] Qtot takes into account any increases caused by thermal bridges (+10%), effects due to intermittence (+10%) and possible additional simplifications adopted in the calculation phase (+10%).

provide to the internal environment in order to keep unchanged conditions of temperature and humidity desired. In particular:

$$q_{tot} = q_{sens} + q_{lat}$$

$$q_{sens} = q_{radiation\ throu\quad windows} + q_{radiation\ throu\quad external\ walls} + q_{trasmission} + q_{internal\ loads}$$

$$^{131}q_{radiation\ through\ windows} = f * A * H$$

$$q_{radiation\ through\ external\ walls} = K_{walls} * A * \Delta T_{equivalent}$$

$$q_{trasmission} = K_{walls/windows} * A * (T_{external} - T_{Internal})$$

$$q_{internal\ loads} = q_{internal\ generators} + q_{ventilation-sens} + q_{people-sens}$$

$$q_{lat} = q_{ventilation-lat} + q_{people-lat}$$

SECOND FLOOR	Qsens	Qlat	Qtot (w)
Kitchen	1782,38	134,72	1917,10
Bedroom1	835,22	136,46	971,68
Bedroom2	887,67	130,58	1018,25
Living Room	1674,53	141,03	1815,56
Studio	736,53	123,32	859,85
TOTAL			**6582,44**

THIRD FLOOR	Qsens	Qlat	Qtot (w)
Bedroom1	855,75	130,33	986,08
Bedroom2	917,86	129,76	1047,62
Kitchen	2571,29	123,85	2695,14
Living Room	1701,06	154,51	1855,57
TOTAL			**6584,41**

Table 49 – Cooling Demand

Therefore, the total demand of the second and third floors in terms of heating and cooling is respectively of about 10kW and 12kW. The same result can be expressed in specific terms of unit area in which one should identify power values typical of a building subjected to thermal refurbishment:

	Heating (W/m2)	Cooling (W/m2)
Second Floor	55	84
Third Floor	74	88

Table 50 – Results

[131] f = shading factor; H = solar radiation

What emerges by now from this result is the confirmation of some important conclusions set out in the previous chapter. In particular, it is important to emphasize that an improvement of thermal performances of the examined building due to a better thermal insulation has led to a reduction of heat losses, and it has mainly stimulated a re-balancing of heating and cooling powers.

The thermal generator chosen is a multi-purpose heat pump with total recovery (model Hiwarm 012 by Galletti Company). This unit is designed to meet the whole home comfort and to contribute to the domestic hot water production. The Hiwarm 012 heat pump in the winter period produces, according to the needs, heat for space heating or hot water for domestic use. In summer, instead, the same produces a double effect since the total recovery configuration allows simultaneously to cool water for the space cooling and to heat the storage tank for the DHW.

1. *Multi-purpose heat pump with total recovery*
   Air to water heat pump for domestic hot water and home comfort.
   - *Cooling power (35°C external air – 7/12°C operative water temperature) = 11.2 kW*
   - *Cooling + DHW (total recovery configuration; 55°C domestic hot water – 7/12°C operative water temperature) = 9.2 kW*
   - *Heating power (30/35°C low temperature for operative water) = 12.2 kW*

The Hiwarm 012 heat pump is flanked by a modular condensing generator (model Alkon R 35 by Unical), which provides heating for pre-existing radiators for the first floor of the building into consideration and contributes to the satisfaction of the domestic hot water demand.

2. *Modular Condensing Generator Alkon 35 R by Unical*
   - *Heating Power = 35 kW*

As can been observed into the following thermal power plant design scheme, two tanks are provided. First, a 1000 litres heat tank by Cordivari was chosen; it is characterized by triple heat exchangers:

- Internal corrugated exchangers for DHW

- Fixed lower exchanger for the heat pump
- Fixed upper exchanger for eventual further external generator

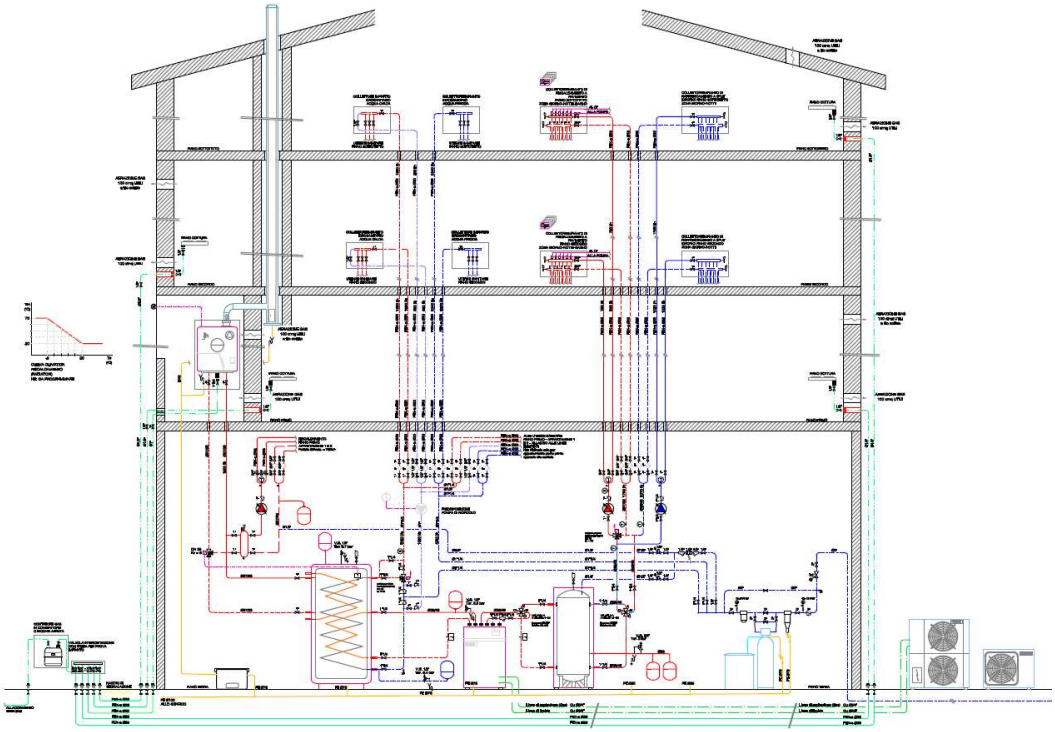


Figure 144 – Thermal Power Plant Scheme

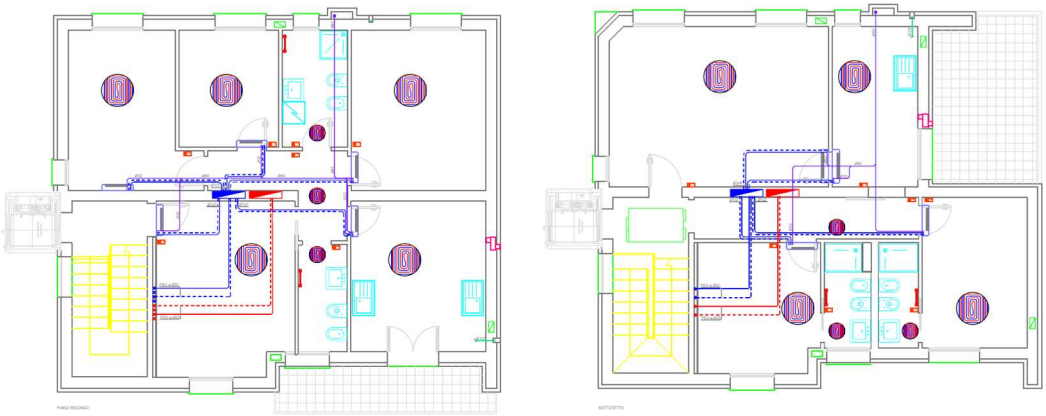


Figure 145 – Plant Views of Heating and Cooling Systems Installed

On the other side, there is a 300 litres heating-cooling tank by Cordivari. This acts as a thermal storage for warm or cold water according to the season. Specifically, two 4-ways valves control the interaction between generator, thermal tank and the distribution system, depending whether the request is space heating or cooling. The plant is divided into two main sections: the first involves the installation of radiant panels with low temperature water

generated by the heat pump in heating configuration. The second part includes hydronic splits by Climaveneta (more congenial for their easier installation and better integration with the existing structure) powered by cold water generated by the same heat pump in the summer polyvalent arrangement.

In conclusion, the design example described confirms the trend according to which systems for multi-family buildings are developing towards centralized solutions that provide both heating and cooling, with the additional interaction with the DHW too. Furthermore, the same shows how electrically driven heat pumps are spreading as alternative to combustion boilers; reversible heat pumps can operate in both winter and summer. The spreading of such generators might push the success of reversible hydronic emitters, like fan coils, split units and radiant panels. In particular, mini-splits, together with fan coils, are supposed to have great success where prerequisites of cheapness and installation facility are going to be predominant. Radiant technology, on the contrary, might gain a prestigious position in the cooling field mainly for new constructions and where wealthier conditions are recorded.

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