ZONED AND NON-ZONED INVERTER SYSTEM IN RESIDENTIAL APPLICATIONS

COMPARISON REPORT

2011

UNIVERSITY OF MALAGA

1. INTRODUCTION 1

1.1. BACKGROUND AND OBJECTIVES 1

1.2. METHODOLOGY 7

1.3. SIZING OF THE UNITS 8

1.4. RESIDENCE MODEL

2. RESULTS

2.1. COMFORT LEVEL

2.2. ELECTRICAL CONSUMPTION

2.2.1. COMPARISON BETWEEN AN INVERTER SYSTEM INTEGRATED WITH ZONING, AND THE SAME SYSTEM WITHOUT ZONING

2.2.2. COMPARISON BETWEEN AN INVERTER SYSTEM INTEGRATED WITH ZONING AND ENERGY MANAGEMENT, AND THE SAME SYSTEM WITHOUT NEITHER OF THEM

3. CONCLUSIONS

4. REFERENCES

1. Introduction.

1.1. Background and objectives.

In developed countries it is estimated that 40% of the energy generated is used in buildings, and in residential, approximately 56% of it is applied to heating and cooling systems. Evidence of growing interest in reducing energy consumption in buildings is the publication in some Spanish regions, such as Andalucia, with regulations that set the rules for an incentive program for sustainable energy development. In Andalucia, this regulation was published on February 4, 2009, and fits the requirements of the Decree 23/2009 of January 27th, establishing the regulatory framework for aid to the environment and sustainable energy development in Andalucia. Specifically, that Order is intended to contribute to improve the environmental protection by promoting energy savings, both in the planning of new facilities, focusing on improving the efficiency of energy in main consumption centers, as well as in specific sectors in which, gradually, there is an increased use of energy

In the residential sector serviced by small and medium power systems all-air units and inverters with direct expansion, through a network of constant flow are commonly used . This type of system is based on the temperature control of a single thermostat, so that the temperature will remain within the range of comfort near the thermostat. As for the other areas of the residence, even when well-designed ductwork and chosen the full power of the computer designer, do not present a load profile similar to that of the controlled area, temperatures can fall outside the range of comfort. Figure 1 shows a schematic of the non zoned system under study.

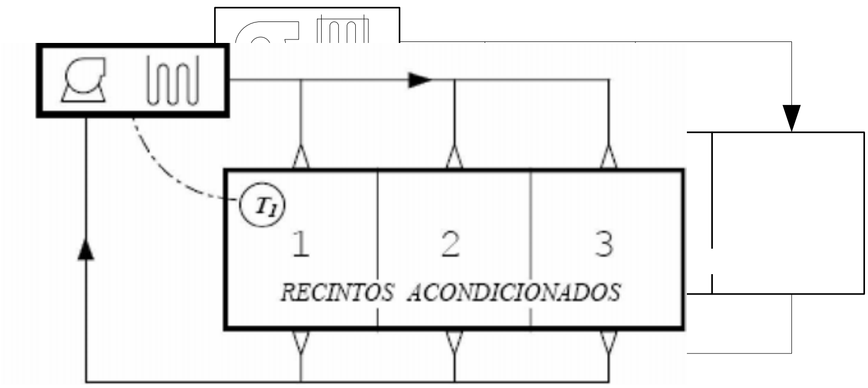


Figure 1: Non zoned system schematic.

As an alternative to these systems, there are air based zoning systems. Unlike the previous system, the zoned system is based on independent temperature control of each of the zones. These systems use motorized dampers, which, when controlled through thermostats, they manage to maintain the required temperature in each zone. As for the air overflow, caused by the air supplied by the fan and not used in some zones, there are two ways to treat it. On one hand, using a variable speed fan to adjust the flow rate to the required air flow by the demanding zones, or to implement a bypass damper to return the excess flow to the indoor unit return. The two zoning systems above are studied in this report, and compared from the standpoint of annual electricity consumption. The idea is to determine the desirability of eliminating or not bypass in these facilities considering the manufacturers trend towards the use of direct expansion units to introduce more and more speed steps to the indoor fan unit. Figure 2 shows a schematic of zoned system with bypass.

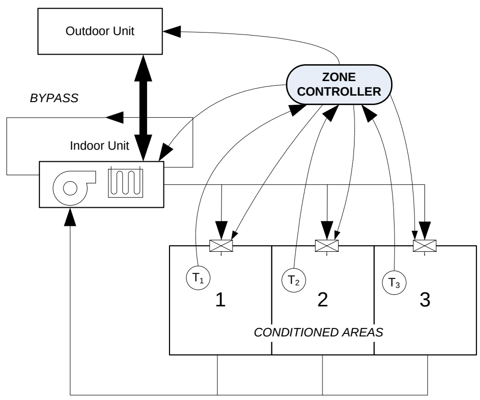


Figure 2: Schematic of a zoning system with bypass.

There are two main advantages in this system of zoning . On the one hand, the unit load is lower since only the zones being used have demand and therefore are heated or cooled. As a result, there are two positive achievements listed below:

1. Inverter units with direct expansion, have three operation regimes. In one of these stages, which is known as working at partial load, the equipment efficiency ratio (COP) improves proportionally to the load reduction on the unit. That is, the lower the load, the higher the COP. Figure 2 shows the performance curve at partial load, that through the tool CalenerBD is defined for the model RXYSQ4PV of Daikin's generation Mini VRV-III.

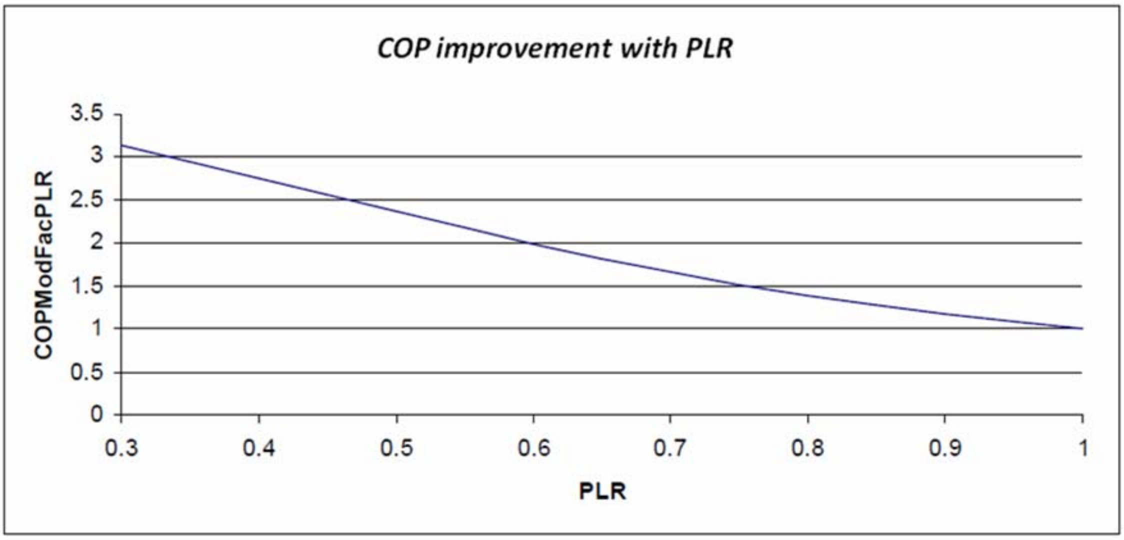


Figure 3: Efficiency rate related with load reduction for an inverter unit

2. The unit will require less power and therefore there will be a lower initial installation cost.

The other advantage refers to the comfort achieved. While with a non zoned system there only one area controlled, in a zoned system the motorized dampers allow us, as long as the AC unit is properly selected, maintain comfort throughout the whole house

As for the drawbacks of the system, all of them are related with the worsening of the efficiency rate. Factors affecting the unit efficiency decline are listed below:

1. The air flow returned to the indoor unit, makes it to work with unfavorable return temperatures. This problem will not appear if we work with a zoned system without bypass.
2. The bypass damper in the system is not ideal, for example, is not able to evacuate all the excess flow that is not driven to zones that are not in demand. This effect generates an overpressure in the duct network, forcing it to work above the range of pressure ratings and for this reason will force to change the indoor fan total impulse flow. In the case of a system without a bypass, as the number of fan speeds is too limited to adapt to all situations, this effect will be also very noticeable.

The experimental trials that the direct expansion units have been go through, have shown that making the coil and indoor fan outside the nominal ranges of temperatures and pressures, causes a reduction of the units' COP .

As known, the power consumption of air conditioning units depend on two factors, the load and the COP.

$$\textit{Electrical Power} = \frac{Q\ total}{COP}$$

Thus, if we analyze separately each of the effects that the zoning system has on the unit, on the one hand we see that we reduce the load, but there are other factors that affect the COP. In this sense, there is the need to obtain a mathematical model of inverter system with zoning that allows us to jointly evaluate these factors and determine if the unit's overall energy consumption increases or decreases in relation to consumption of an inverter unit not zoned.

Currently there is no a tool available that can calculate the savings that an inverter unit integrated with zoning with or without bypass can be achieved with respect to the same unit without zoning. Thus, the proposed work will proceed considering a multizone system with a detailed formulation of the mechanisms of heat transfer in buildings that are matched with an inverter air conditioning system, to simulate actual operating conditions. The difference with other programs to compute workload, lies in the fact that through this matching, it si s possible to identify which zones are or not in demand, and thus to pose an evolution of the thermal balance, free of the temperature in the inactive zones. This effect is of great importance, as it makes that there will be variations in the boundary conditions of the zones if they remain active, and therefore the thermal load of them will be altered in reference with the basic calculation in which all spaces are air conditioned.

Altra Corporation, through its division Airzone, a manufacturer of air-zoning without bypass and integrated to inverter units, aims to assess the suitability of this type of system, from the standpoint of the user's comfort, thermal power provided and annual electrical energy consumption, compared to an inverter unit without zoning. The Integrated Zoning systems developed by Altra Corporation, through its division Airzone, vary from the standpoint of control. Thus, the comparison is made taking only some of them. That will help us to determine the difference between them and to know which control strategies produce more important savings in annual electricity consumption.

The systems implemented are listed below:

1) <u>Zone control system with communication Gateway</u>

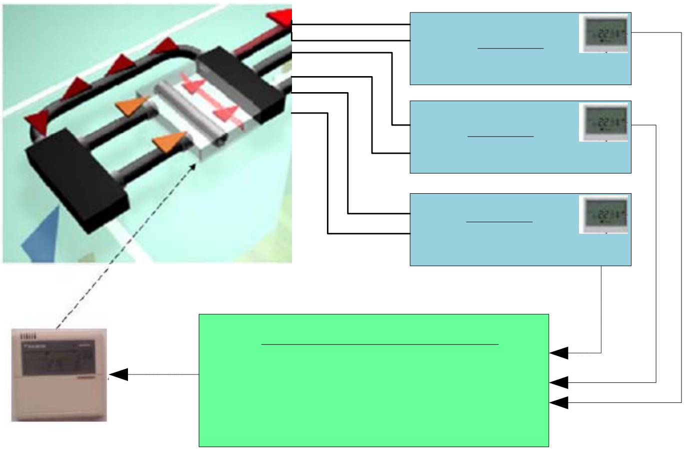
The main advantage of this system is the use of a communication gateway between the zoning system and the air conditioning thermostat. Thus, from the control board of the zoning system, we can control the following variables:

1. *Mode:* The AC unit operating mode (cooling, heating or ventilation). It will be the required by the most demanding areas. Those areas that are in thermal inversion, for example, if the system operated in the opposite mode to which that zone claims, it will be kept closed.

2. *AC unit Temperature setpoint*: The system will adopt the mínimum or máximum temperature defined by the user in the active zones, according to the operation mode (cooling or heating respectively).

3. *Indoor fan speed*, because the air conditioning equipment usually have two fan speeds, we will set one or the other depending on the number of hotspots at a given time. The criteria is to set the fan speed depending on the percentage of active zones related to the total number of zones, considering that the master zone, which is usually the one with higher thermal demand, is twice the weight of any other. That is, in the evaluation of the number of zones on demand, all areas have a value equal to unity, while the master zone is worth two.

Figure 4 shows a diagram of the information exchange between the AC unit thermostat and zoning system communications gateway *Figure 4: Zoning system with*



communications gateway.

The introduction of multi-step indoor unit fan, suggests the feasibility of eliminating the bypass damper, and convert the inverter system with integrated zoning and bypass in a variable flow system. In this sense, we will evaluate the same control system with integration between the AC unit and the system, in an installation with and without bypass. The only difference between the two models will be on the method for calculating the supply flows per zone. This has forced us to verify the same installation, with and without bypass, and determine the difference, in terms of changes in pressure and air flow, between the two models.

2) Zoning system with communication Gateway and Energy control system

On November 27, 2009, it was published in the Spain's Official Bulletin (BOE) the Royal Decree 1826/2009 amending Regulation of Thermal Installations in Buildings (RITE). This Royal Decree establishes the limitations on how to enter indoor temperature to keep the premises habitable in winter and summer. Specifically, it sets a minimum temperature in summer of 26 ° C (79 ° F), and 21 ° C (70 ° F) in winter.

In this regard, with the aim of following the trend set by the Royal Decree, the , Altra Corporation, through its division Airzone, sets the idea of energy management in inverter units with direct expansion using two control possibilities. The hypothesis followed by each of them are defined following:

A. *Blueface*: This energy management system, regardless the behavior of the system, restricts the temperature setpoint for each zone as defined in the RITE, or better. For example, temperatures above 26 ° C (79 ° F) in cooling mode or under 21 ° C (70° F) in heating mode. This management system is very useful in public buildings installations, where the temperature set point indicated by the Royal Decree are mandatory. This is not the case for residential, and to convince the user to maintain the same temperature set points always can be somewhat complicated. For that reason, another management system was developed, in which part of the temperature setpoint is defined by the user, and only they will modified in situations where the unit needs to work at full load. This management system, known as Enerface is defined below.

B. *Enerface:* Unlike the previous management system, Enerface is a less restrictive from the point of view of comfort. Its objective, will be the evaluation of the unit's operating conditions, and knowing its behavior at different operating points, to configure the air conditioning system so that it will always operate at the maximum efficiency point.

The algorithm required to accomplish the maximum efficiency will be integrated into the communications gateway, which is placed between the zoning system control board and the inverter air conditioning equipment. Therefore, it will have the information on the performance required by the user and the response that it generates on the unit. Thus, the evaluation of this response, which will allow the system to establish the cases in which the algorithm will take control of the unit's performance. In case of obtaining an acceptable response, the user's setting will overwrite the algorithm's setting suggestion. Thus, unlike the proposed control by RITE, the energy saving algorithm will only modify the operating conditions required by the user in certain situations, and will not interfere on other situations. This idea will lead us to achieve a reduction in the electricity consumption of the equipment at the same time that it will maintain, as long as possible, the conditions set by the user for comfort.

Among the variables processed by the algorithm, the more important for the final decision is the unit's power consumption. To register this data, it has been added a current sensor to the control board of zoning system. That sensor will provide information about the intensity of electric power consumption, and then comparing it to the maximum specified by the manufacturer, will allow us to know the unit work factor at partial load (PLR).

According to the definitions in the previous paragraph, if in addition to the thermal demand reduction achieved through a zoned system, it is added to it a set point temperature management algorithm, it will be possible to reduce even more the partial load factor, resulting a better efficiency ratio coefficient.

1.2 METHODOLOGY.

The monitoring and recording of the operating parameters of the proposed systems for later comparison, is costly and complicated due to the need to compare several different air conditioning systems under the same conditions of operation over an extended period of time, (at least one year), and in different locations. For this reason, we opted for the thermal simulation of buildings as it provides a reliable and economical alternative.

This study has been accomplished by use of one of the most advanced simulation software in the market, TRNSYS. Using this calculation platform, it have been implemented mathematical models for all air conditioning systems as defined in the previous section. These models have been obtained through experimental testing of a direct expansion unit in a double climate chamber. This chamber is composed of two separate but adjoining chambers but independent in terms of operation, since they can be programmed to ensure different temperature and humidity conditions. In this sense one of them will have the outdoor unit and the other the indoor unit, as shown in Figure 5.

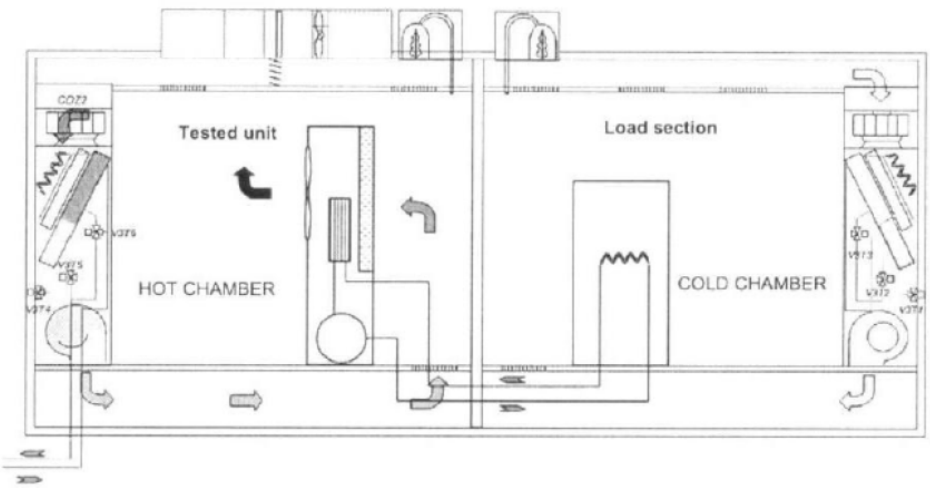


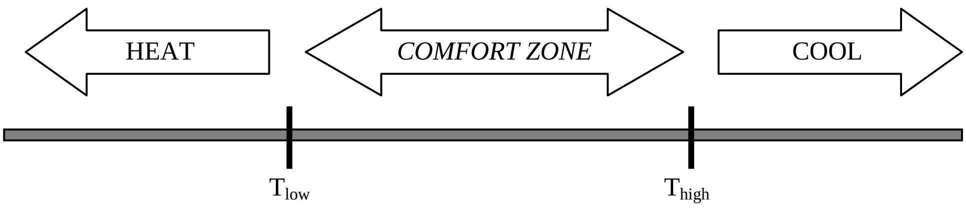
Figure 5: Location of the direct expansión unit inside the climate chambers

Both climate cameras are connected to each other and with the exterior, which allow the layout of the coolant pipes and sensors wirings.

Thus, the variation of nominal properties of unit, maximum load and COP, can be registered, depending on temperature and moisture content of the return air to both coils, besides of the airflow (CFM) of the indoor fan. The idea is to determine the behavior of the unit within range of conditions that it would be working in an actual installation.

1.4 Dimensionado de los equipos seleccionados.

The size of the unit under study, will be done considering that the users comfort temperature range, will be between 23°C and 24°C (73°F and 75°F). Thus, if the free evolution of the temperature in any zone remains within the margin of comfort, the air conditioning system will remain off. On other hand, if the temperature is above or below the established ranges, the system will operate in cold or heat, respectively. Thus, when the unit is operating in heating mode, it tries to keep the temperature controlled zone at 23°C (73°F) and



when in cool mode, at 24°C (75°F).

Figure 6: Definition of the operating work ranges related to the ambient temperatures

In a non-zoned installation, the air distribution ductwork does not have any element that allows dealing with the needs of individual each area. Thus, to ensure the possibility to cover the peak load in all of them, the unit's power rating should be equal to or greater than the sum of the peak load areas although they may not be simultaneous.

Thus, the values of the thermal demands in the different locations used for the study are summarized in Tables 1, 2 and 3. In them, positive values indicate cooling loads and negative values, heating loads.

RID						
LOADS	VING	TCHEN	T. BED	DROOM	FFICE	TAL MAX LOADS
$Q_{COOLING}$ (W)	2240	1474		1090	1147	**7646**
$Q_{HEATING}$(W)	2146	-2296	5	-874	-1342	**-7793**

Table 1: Summary of peak loads in a simultaneous non-inverter system is not zoned for the city of Madrid.

BARCELONA						
LOADS	VING	TCHEN	T. BED	DROOM	FFICE	TAL MAX LOADS
$Q_{COOLING}$ (W)	2073	1185	1622	1011	1000	**6891**
$Q_{HEATING}$(W)	1656	1800	-856	-666	-1044	**-6022**

Table 2: Summary of peak loads in a simultaneous non-inverter system is not zoned for the city of Barcelona.

VALENCIA						
LOADS	VING	TCHEN	T. BED	DROOM	FFICE	TAL MAX LOADS
$Q_{COOLING}$ (W)	2033	1259	1574	993	1013	**6872**
$Q_{HEATING}$(W)	1519	-1696	-777	-612	-951	**-5554**

Table 3: Summary of peak loads in a simultaneous non-inverter system is not zoned for the city of Valencia.

According to this load review, Mitsubishi's model PEHD-RP125GA, with a nominal cold-sensitive load of 8610W, and 13,900 W in heat, will cover the needs of the building in the three locations under study. Its characteristics are summarized in the Table 4.

aracteristics	Value	Units
$Q_{Cool\ total}$	12300	W
COP_{Cool}	2.49	
SHR	0.7	
Qsens cool	8610	W
Qtotal heat	13900	W
COP_{heat}	2.89	
$C_{nominal\ high}$	2520	m3/h
$C_{nominal\ low}$	2010	m3/h

TablE 4: Characteristics of the selected unit.

In contrast, in a zoned system, the air distribution ductwork has motorized dampers that

adjust the system's thermal supply to the demand of each zone independently. Thus, the unit should be
sized considering the maximum zone's simultaneous loads. Table 5 shows the values of the simultaneous peak load of each of the cities under study, where the values indicate loads positives for cooling and negatives values for heating

imum simultaneous loads	CITY		
	Madrid	Barcelona	Valencia
$Q_{COOLING}$ (W)	6129	5505	5322
$Q_{HEATING}$(W)	-7883	-5929	-5545

Table 6: Summary of maximum simultaneous load for the cities under study.

According to this load review, Mitsubishi's model PEHD-RP100GA, with a nominal cold-sensitive load of 6720W, and 10,300 W in heat, will cover the needs of the building in the three locations under study. Its characteristics are summarized in the Table 6.

aracteristics	Value	Units
$Q_{Cool\ total}$	9600	W
COP_{Cool}	2.41	
SHR	0.7	
Qsens cool	6720	W
Qtotal heat	10300	W
COP_{heat}	2.81	
$C_{nominal\ high}$	1980	m3 /h
$C_{nominal\ low}$	1560	m3 /h

Table 7: Characteristics of the selected unit..

Thus, for the selected dwelling, the results implicate that the use of a zoned system involves the power reduction for the selected unit. If we choose a bigger model, the unit would be oversized and would not take full advantage of its inverter operation regimen. As is known, the mass flow of refrigerant can not be made arbitrarily small, and there is a minimum speed for which the unit stops working as an inverter system and becomes an ON/OFF system. This action of reducing the unit's power, is aimed to avoid such situations

1.5 Dwelling model.

The simulated housing in the cities of Madrid, Valencia and Barcelona, is a house whose floor piano and orientations shown in Figure 7

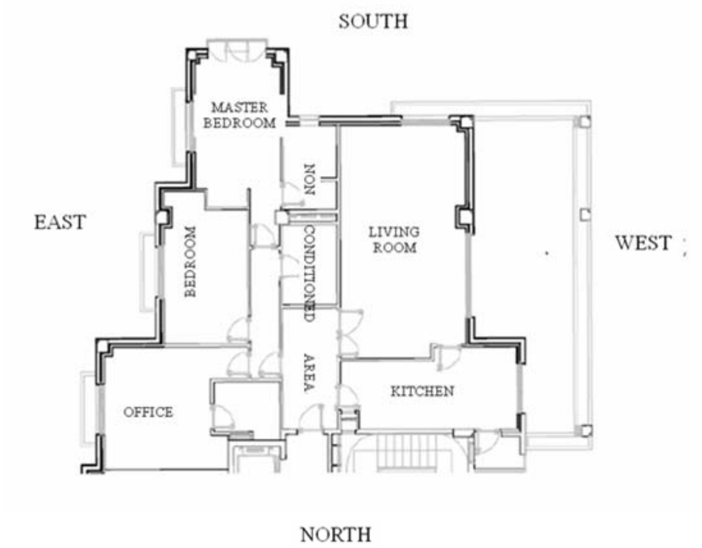


Figure 7: Dwelling plant

As shown, the house has five air-conditioned areas (living room, kitchen, office and two bedrooms, and the rest is considered a single unconditioned area. The surface of the conditioned area is 121 m2 (1,302 sq ft), which are distributed as shown in Table 7.

Area m² (sq ft)				
Living room	*Kitchen*	*Master bedroom*	*Bedroom*	*Office*
38.7 (415)	1.1(227)	8.6 (200)	18.6 (200)	4 (258)

Table 7: Areas of each of the zones in the dwelling under study

Since in a zoned system is the demand of unoccupied zones is not served, it is important to determine the usage profile of each zone. Table 8 explains the usage profile used.

	ving room	Kitchen	Office	Bedroom	Master bedroom
0:00-7.00	0	0	0	1	1
7:00-7:30	0	1	0	1	1
7:30-8:00	0	1	0	1	1
8:00-10:00	1	1	0	1	0
10:00-16:00	1	1	0	1	0
16:00-17:00	1	1	0	0	0
17:00-20:00	1	1	1	0	0
20:00-20:30	0	1	0	0	0
20:30-23:00	1	0	0	0	1
23:00-24:00	0	0	0	1	1

Table 8: Dwelling zones use profile.

2. Results.

Once defined the dwelling characteristicas and the inverter air conditioning unit, we insert the unit in the home to obtain, in each time step of the simulation, the indoor conditions in all zones and unit's operation data (thermal power supplied, power consumption, COP , etc.). as well as the value of all flows heat and mass used.

As defined in the introduction, the objective of this study is to compare the convenience of using a zoning system integrated to an inverter unit with different control configurations proposed by the Altra Corporation, with an inverter system without zoning. The benchmarks we use for the comparison are annual electric consumption and the degree of comfort provided by each system. Thus, this section will be divided into two parts, the first checks the comfort level provided, and the other will study the annual power consumption associated in each situation.

According with the experimental results, in a zoned system, the effect of overpressure that happens in the air supply ductwork due to the opening and closing of the zones, causes a reduction of the unit's COP. This reduction in the COP is defined experimentally when the unit is working at full load, but its influence on partial load behavior has not been verified. In addition, the HVAC equipment manufacturers do not provide information about that. Given this lack of information, it was decided not to consider this effect on equipment performance at partial load, and use the full load data.

Besides the above, the calculation assumptions considered in the proposed models are listed below:

1. The ductwork is assumed adiabatic, meaning that it is well insulated and therefore there will be no loss of energy through it.
2. There are not changes in the temperature set point from the user, considering that any criteria in that sense it would be arbitrary. In contrast, the energy management systems will be able to change the temperature set point, according to the control hypothesis defined in the

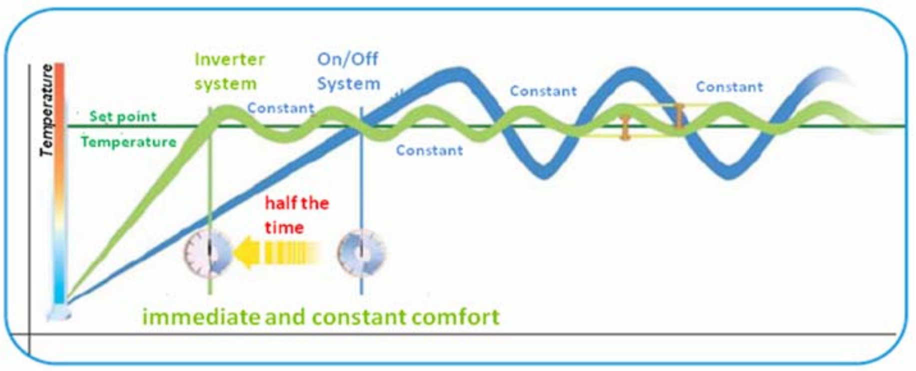
introduction.

3. It is considered that all areas are in overpressure and therefore there will not be infiltration. This is done by returning an amount of air less than the supplied to each zone.

4. The return is considered ducted and like the supply duct, it will be fully adiabatic.

5. No air exchange between the zones, except through the indoor unit.

6. The calculation of the various proposed models of air conditioning has been performed considering stationary conditions. This means that at each step of the simulation, we consider that the system maintains a constant response, without taking into account the dynamic evolution to reach this steady state. This effect is more important in the on and off processes of the unit. As we can see in figure 8, in these situations, the computer takes some time to



reach the required operation regime.

Figure 8: Evolution of the start cycle of an air conditioning unit.

The time to reach constant regime in the unit has been greatly reduced in the inverter product.

2.1 Comfort level.

The situations in which there is discomfort in a given zone, and therefore had been considered for this study are listed below

1. At every time, the unit only works one mode, so the system cannot cope with simultaneous temperature inversions that may happen in the home.
2. The unit may have power limitations. The unit was selected based on their nominal power but the different working conditions make that in some situations, it may not cope with the total demand

3. In the situation of a non zoned system there is only one area with controlled temperature. Thus, the remaining areas in which there is not a load profile similar to that of the controlled area will remain in discomfort.
4. In a zoned system, the discomfort hours of are due to the time to bring the zone to regimen, which in previous time steps was unoccupied. The thermal inertia to overcome will be high, and in some cases the zone demand of an area will exceed the peak load used to choose its mass flow. As a result, the system is not able to supply the zone the total required energy and it will take longer to bring the ambient temperature to the desired setpoint. This effect can be seen in Figure 9, which shows the temperature evolution of the office on June 14 in Madrid.

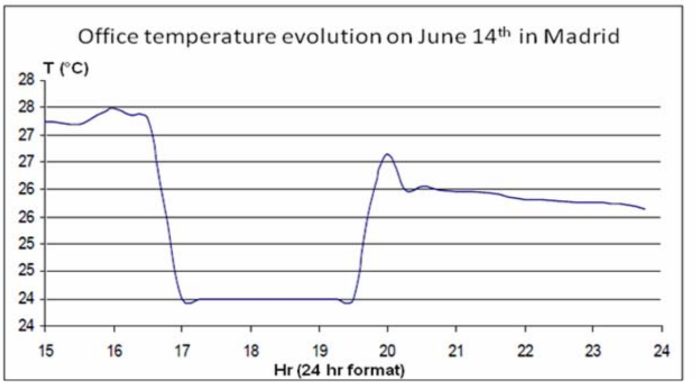


Figure 9: Office temperature evolution on June 14th in Madrid.

The not zoned system control depends on the Living room demand according with the comfort range setting, with conditions in other zones depending on the environmental conditions at each moment.

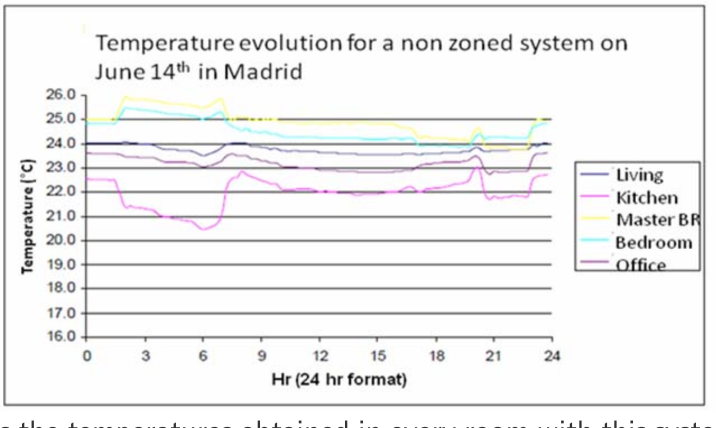


Figure 10 shows the temperatures obtained in every room with this system .

Figure 10: Temperature evolution for a non zoned system on June 14th in Madrid

As shown, the temperature of the living room stays in the setpoint of 24 ° C. The oscillations that happen are concentrated in the range from 23.5 to 24 ° C, which is the range that has been used in the model to define the system demand, and thus to reduce the number of iterations performed by the software and therefore reduce the computing time. The temperature of the other models will vary depending on the definition of the demand profile. In this graphics it can be verified how the kitchen experiences a significant increase in temperature at 20:30, at which it is occupied according to the profile defined for the housing use, when the whole family gets together for dinner. This effect, although to a lesser extent can also be seen in the other zones. Unlike the non zoned system, with a zoned system the temperature control is done separately for each zone and climatization is stopped in unused zones.

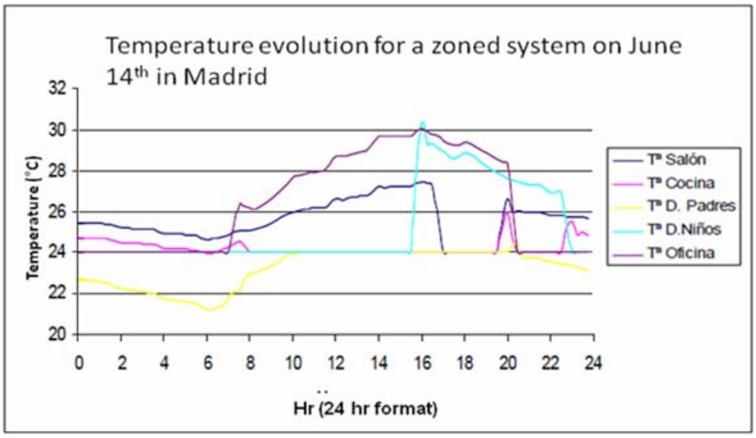


Figure 11: Temperature evolution for a zoned system on June 14th in Madrid

Figure 11 shows a thermal inversion phenona in the kitchen. According with the profile defined in the home occupation, the kitchen is used from 7 AM, and its temperature is below 23 °C (73 °F) and therefore it is demanding heat. Since there are two other areas (master bedroom and bedroom), demanding cold and one zone demanding heat, the system will operate in cooling mode and to avoid the kitchen to be overcooled, it will close its damper.

Table 9 shows the comfort percentages achieved by each system in the three sites under study. To obtain it, the time steps that the system works in cold and heat have been considered according with the thermal comfort range defined in the graph below. Thus, the study of comfort does not take into account those situations where the unit is off, the temperature zones are maintained within the comfort range. In those cases where the unit is operating, we define a 1 °C (2 °F) hysteresis centered on the selected temperature to determine if the zone is at comfort level.

CITY	ZONE	TIME WITHIN THE CONFORT RANGE(%)			
		ZONED SYSTEM		NON ZONED SYSTEM	
		ol Mode	eat Mode	ol Mode	Heat Mode
MADRID	Living	97.9 %	93.6 %	84.0 %	88.6 %
	Kitchen	99.9 %	96.0 %	0.5 %	42.4 %
	aster Bed	98.8 %	98.6 %	49.8 %	8.8 %
	edroom	97.8 %	98.0 %	80.5 %	25.9 %
	Office	92.6 %	89.0 %	21.7 %	51.1 %
ARCELONA	Living	98.1 %	96.4 %	99.7 %	91.2 %
	Kitchen	99.8 %	97.5 %	1.9 %	53.4 %
	aster Bed	98.9 %	98.6 %	48.4 %	17.0 %
	edroom	98 %	98.0 %	83.12 %	43.7 %
	Office	93.0 %	91.9 %	38.0 %	68.5 %
VALENCIA	Living	98.1 %	96.3 %	98.8 %	90.3 %
	Kitchen	99.8 %	97.5 %	1.1 %	58.5 %
	aster Bed	98.9 %	98.6 %	42.8 %	16.7 %
	edroom	98.1 %	97.9 %	77.7 %	41.4 %
	Office	92.9 %	92.3 %	35.6 %	68.0 %

Table 9: Time within the confort range for both systems.

According with the results, the non zoned system only capable to grant a high percentage of comfort level in the controlled zone, in this case the living room. On the other hand, the zoned system is capable of securing comfort in all areas independently. Only in the office the comfort level in both modes was below 95%. This is due to the large thermal inertia to be overcome as a consequence that it is enabled only 3 hours a day, from 17 to 20 h (see table 8).

2.2 Power consumption.

The next section will be subdivided into two parts. On one hand, we compare the annual results of thermal demand, COP and power consumption for systems non zoned inverter systems and inverter system integrated with zoning, but without any energy management system. Later, we will define the same outcomes associated with the two power management systems that are defined in the introduction.

2.2.1 COMPARISON OF A NON ZONED INVERTER UNIT AND THE SAME INVERTER INTEGRATED TO A ZONED SYSTEM.

Tables 10 and 11 show the results for the comparison of these systems for different cities under study.

CITY	SISTEM	COOL MODE				HEAT MODE		
		QTOTAL Wh/year	QSENSIBLE Wh/year	nsumption kWh/year	O P	QTOTAL Wh/year	nsumption Wh/year	OP
adrid	Zoned	6474	6458	1887	.43	12129	3646	33
	n Zoned	7991	7987	2431	.29	16253	4136	93
celona	Zoned	5973	5972	1677	.56	7867	2192	59
	n Zoned	7486	7424	2244	.34	11255	3078	66
lencia	Zoned	7688	7675	2096	.67	5948	1760	38
	n Zoned	10453	9890	3103	.37	8971	2501	59

Table 10: Demand, annual power consumption and COP of the not zoned system inverter and inverter with integrated zoning

			YEARLY POWER SAVINGS			INGS IN THE YEARLY THERMAL	
CITY	SISTEM	Total (kWh)	avings Cool (%)	avings Heat (%)	Total vings (%)	Cool ings (%)	Heat vings (%)
Madrid	Zoned	5533	22.4%	11.8%	15.7%	19.1%	25.4%
	on Zoned	6567					
arcelona	Zoned	3869	25.3%	28.8%	27.3%	19.6%	30.1%
	on Zoned	5322					
alencia	Zoned	3856	32.5%	29.6%	31.2%	22.4%	33.7%
	on Zoned	5604					

Table 11: Thermal demand savings Percentage and power consumption of the inverter system integrated with zoning against a non-zoned inverter system.

According to these results could draw the following conclusions:

1. The inverter system integrated with zoning, besides increasing the degree of comfort in all areas of dwelling, is able to secure an annual power savings between 15 and 31% in the cities of Madrid and Valencia respectively.
2. The inverter system integrated with zoning provides a reduction in thermal demand of around 25% compared to a non zoned inverter system. This value of thermal demand reduction is in agreement with the results of the annual power savings indicated above.
3. The inverter system integrated with zoning achieves greater demand reduction in the thermal demand required to satisfy the heating mode. This is because the heating demand is higher during the winter nights, when the zoned system only have to satisfy the demand for the bedrooms. Thus, the savings resulting from not conditioning the rest of the house is more important. On the other hand, the maximum demand for cooling happens during the middle of the day, at which happens the maximum occupation of the zones in a zoned system. These facts can be seen in Figures 12 and 13, which compares the levels of thermal demand for both systems.

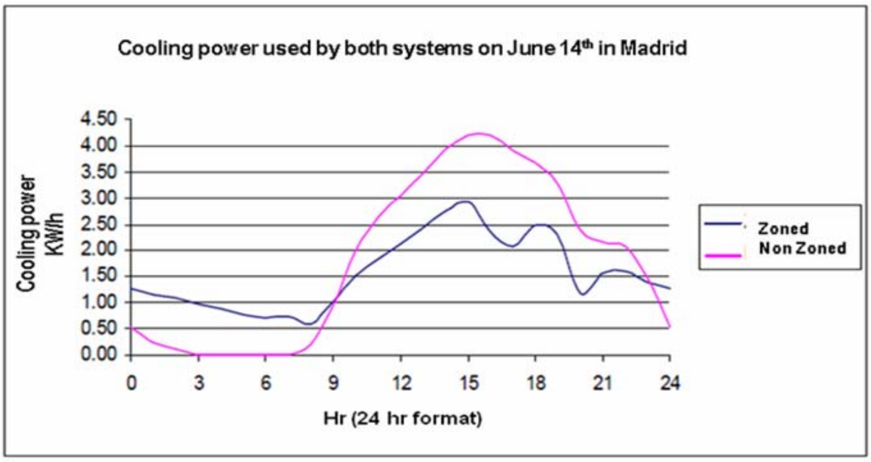


Figure 12: Comparison of the thermal cooling demand of the inverter system with integrated zoning and a not zoned inverter system for June 14th in the city of Madrid

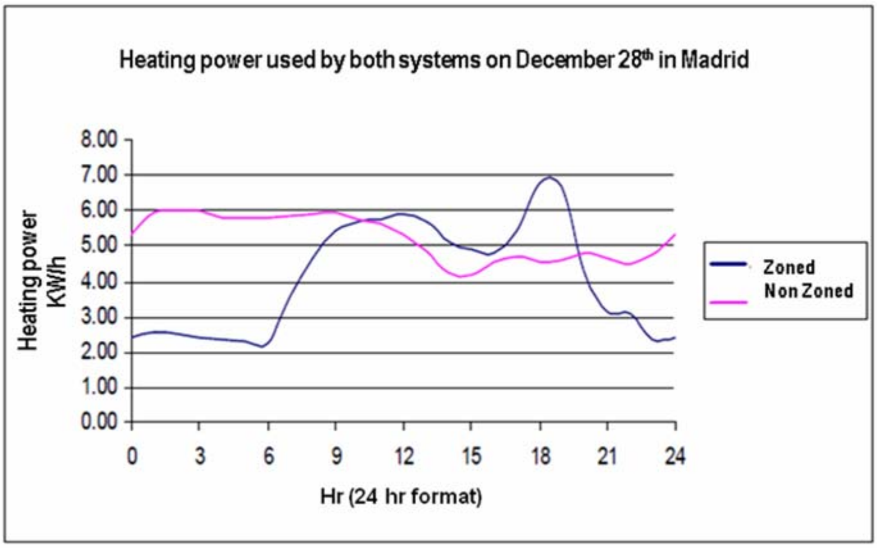


Figure 13: Comparison of the thermal heating demand of the inverter system with integrated zoning and a not zoned inverter system for December 28h in the city of Madrid

Despite the greater reduction in the thermal demand in the heating mode, except for the city of Barcelona, the annual energy savings achieved in cold mode are higher. The explanation is found in the performance curve of the inverter unit at partial load and its lower working limit. As defined in the introduction, the inverter units improve the COP when the partial load factor (PLR) is reduced, up to a limit value of PLR= 0.25. Below it, the unit behaves as an ON/OFF system and therefore its COP worsens. Because, in all studied locations, the unit has been sized based on the cool demand, the unit is over dimensioned for heating mode. In these cases, the nominal capacity of heating is much greater than the thermal demand, and therefore the number of time steps in which the system operates below the lower limit of the PLR increases with respect to a non-zoned system.

4. Finally, the unit's efficiency ratio (COP) improves in cooling mode and worsens in heating mode, compared to a non-zoned inverter system. This is because the explanation above. The significant reduction in the thermal demand in the heating mode, in an inverter unit integrated with a zoning system, increases the number of hours the unit works below the adjustable limits of the unit.

   The zoning system that we have compared in this section is a system with a bypass damper. As defined in the introduction, the increase of the number of speed steps of the indoor fan unit, allows to consider the possibility of eliminating the bypass and consider the system without it. For this reason, we decided to integrate the system model without bypass in the same dwelling, and determine their behavior in terms of annual electricity consumption for comparison with the system with bypass . The comparison of both systems has been conducted under the same conditions, assuming that in both cases there is an integration gateway between the unit and the zoning system, and that the unit has two speed steps. The results are summarized in Tables 12 and 13.

CITY	*SISTEM*	*COOL MODE*				*HEAT MODE*		
		Q_{TOTAL}	*$Q_{SENSIBLE}$*	*nsumption (Wh/year)*	*O P*	*Q_{TOTAL}*	*nsumption Wh/year)*	*OP*
ladrid	*o Bypass*	6493	6457		52	12065		36
	Bypass	6474	6458		43	12129		33
rcelona	*o Bypass*	5979	5972		70	7864		78
	Bypass	5973	5972		56	7867		59
lencia	*o Bypass*	7711	7674		69	5947		57
	Bypass	7688	7675		67	5948		38

Table 12: Yearly demand, power consumption and COP of the zoned system with a communications gateway with and without Bypass.

			YEARLY POWER SAVINGS		
CITY	SISTEM	Total (kWh)	Savings Cool (%)	Savings Heat (%)	Total Savings (%)
Madrid	No Bypass	5440	2.1%	1.4%	1.7%
	Bypass	5533			
arcelona	No Bypass	3696	3.7%	5.0%	4.4%
	Bypass	3869			
Valencia	No Bypass	3758	0.2%	5.2%	2.5%
	Bypass	3856			

Table 13: Percentage of power savings electric of a zoning system with communications gateway with and without bypass

According with the results, the yearly power consumption of the inverter system integrated with zoning with and without bypass, Shows an improvement of about 2.5% annually. By eliminating the effect of COP degradation due to the ductwork over pressure, the main difference between the two systems is the air temperature returning to the indoor unit. This effect is more unfavorable in a bypass system, and this is the reason for the small increase in the annual power consumption

Since it has been shown that the same system with zoning integration presents a better annual energy performance by eliminating the bypass, from now on in this part of the study, all inverter units integrated with zoning will be considered without bypass.

2.2.2 *COMPARISON OF THE NON ZONED AND ZONED SYSTEM WITH AN ENERGY MANAGEMENT SYSTEM*

The two energy management systems we have consider in the following section are those known commercially as Arizone's Blueface and Enerface. The first keeps the setpoint temperatures fixed in all areas according with RITE requirements. On the other hand, Enerface will look into the unit operating conditions, and knowing its behavior in different work situations, it will control the system forcing it to be always working at the point of maximum efficiency.Thus, we reduce the number of hours working at full load and at the same time improving the operation at partial load. The results, when compared the inverter system integrated with zoning and without bypass zoning with a not zoned inverter are summarized in Table 14.

CITY	SYSTEM	COOL MODE				HEAT MODE		
		Q_{TOTAL} (kWh/year)	$Q_{SENSIBLE}$ (kWh/year)	sumption Wh/year	OP	Q_{TOTAL} (kWh/year)	sumption Wh/year	OP
MADRID	BlueFace	4787	4787	1280	74	9514	2623	63
	Enerface	5857	5857	1469	99	11267	2899	89
	Zoned	6493	6457	1846	52	12065	3594	36
	Non Zoned	7991	7987	2431	29	16253	4136	93
ARCELONA	BlueFace	4203	4203	1091	85	5483	1533	58
	Enerface	5414	5410	1374	94	7648	1924	98
	Zoned	5979	5972	1615	70	7864	2081	78
	Non Zoned	7486	7424	2244	34	11255	3078	66
VALENCIA	BlueFace	5611	5611	1463	84	3930	1153	41
	Enerface	6768	6742	1648	11	5833	1578	70
	Zoned	7711	7674	2091	69	5947	1667	57
	Non Zoned	10453	9890	3103	37	8971	2501	59

Table 14: Demand, annual power consumption and COP zoning system of the inverter system with zoning integrated with and without energy management system, and for a not zoned inverter system.

Table 15 shows the savings percentages of the three inverter ystems with integrated zoning in reference to non-zoned inverter unit

CITY	SISTEM	Total (kWh)	YEARLY POWER SAVINGS			INGS IN THE YEARLY THERMAL	
			avings Cool (%)	avings Heat (%)	Total vings (%)	Cool ings (%)	Heat vings (%)
Madrid	Blueface	3903	47.3%	36.6%	40.6%	40.1%	41.5%
	Enerface	4368	39.6%	29.9%	33.5%	26.7%	30.7%
	Zoned	5440	24.1%	13.1%	17.2%	19.2%	25.8%
arcelona	Blueface	6567	51.4%	50.2%	50.7%	43.4%	51.3%
	Enerface	2624	38.8%	37.5%	38.0%	27.1%	32.0%
	Zoned	3298	28.0%	32.4%	30.6%	19.6%	30.1%
alencia	Blueface	3696	52.9%	53.9%	53.3%	43.3%	56.2%
	Enerface	5322	46.9%	36.9%	42.4%	31.8%	35.0%
	Zoned	2616	32.6%	33.3%	32.9%	22.4%	33.7%

Table 15: Percentage of power energy saving for systems with integrated zoning related to non zoned inverter System

Figures 14 and 15 show these results graphically, so that it can be seen the different steps to improve energy efficiency of the inverter systems integrated with zoning in comparison with a traditional non- zoned system.

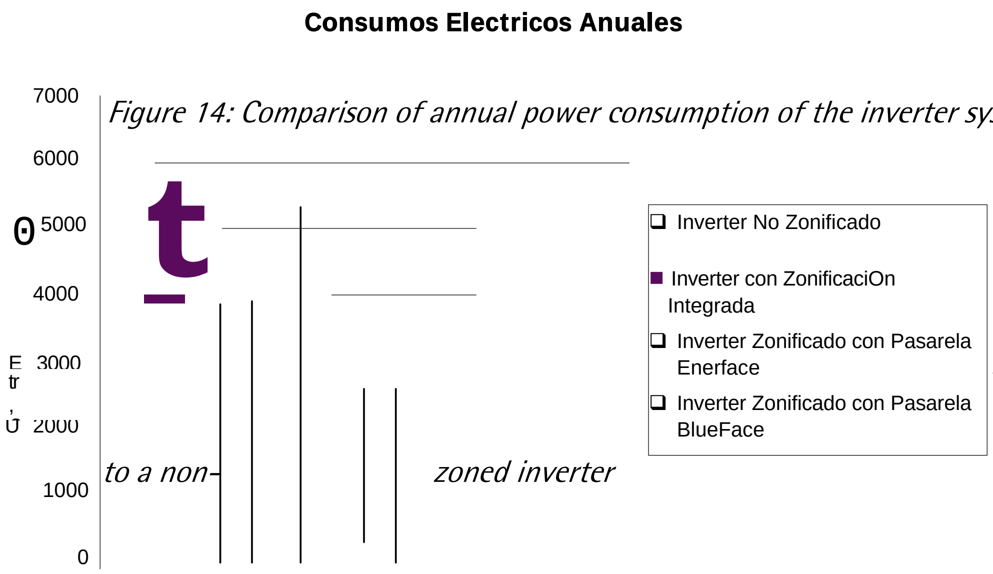
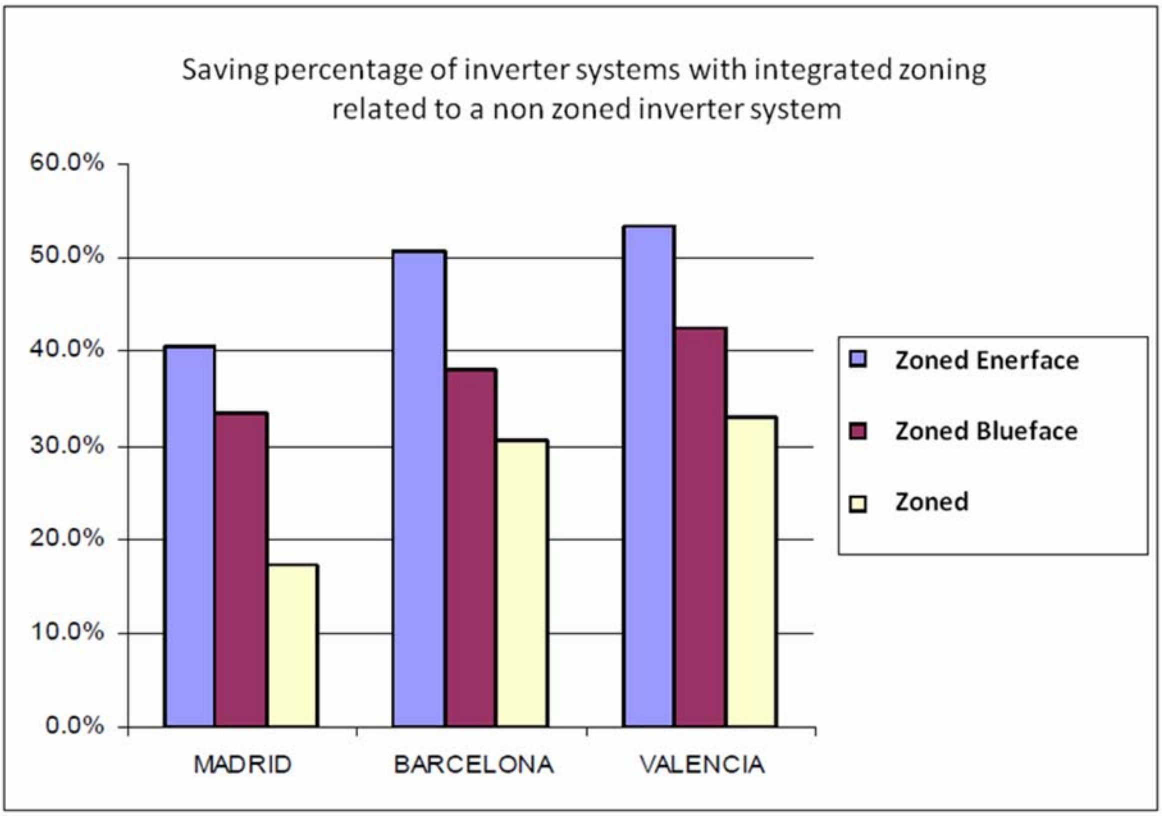


Figure 14: Comparison of annual power consumption of the inverter systems with integrated zoning, with and without energy management system, compared to a non-zoned inverter system



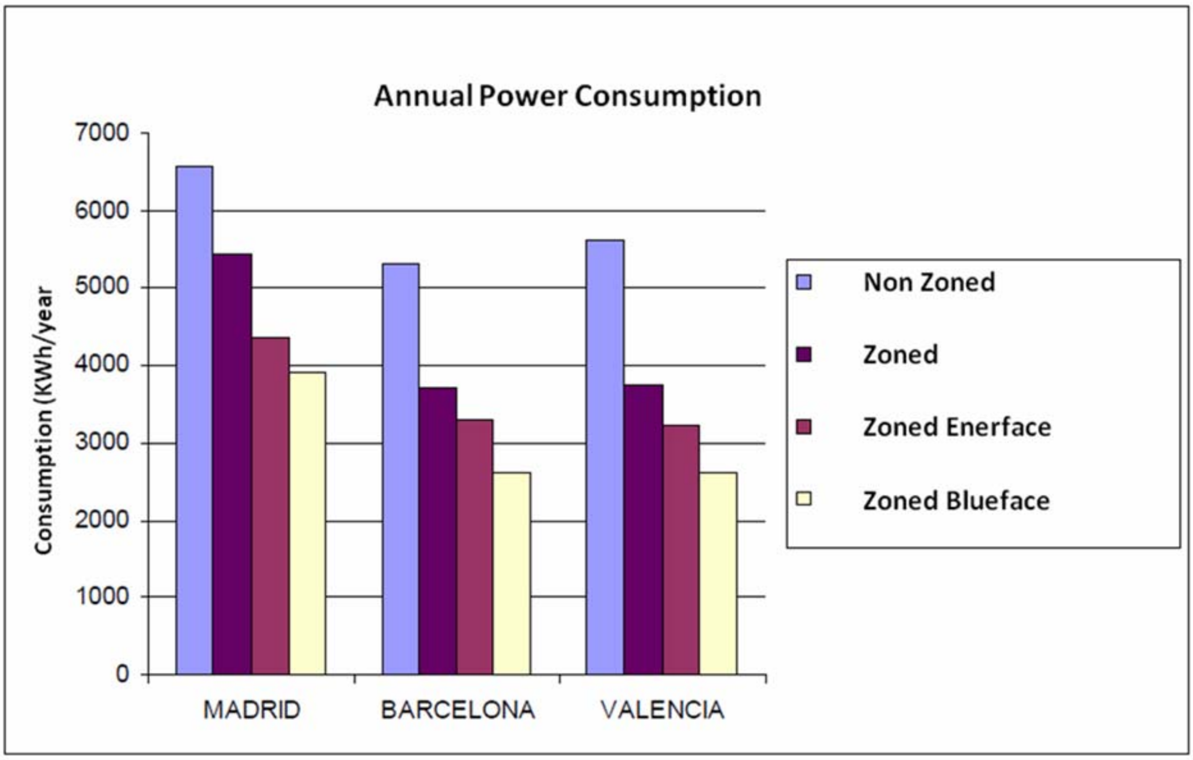


Figure 15: Comparison of annual energy savings of zoning systems studied versus non-zoned system.

The saving percentages have been obtained by setting as a reference the non zoned inverter system. However, in the table below, those percentages are defined related to the savings of a inverter system with zoning. Thus, it can be appreciated the degree of improvement contributed by the new energy management systems (Enerface and Blueface).

			YEARLY POWER SAVINGS			INGS IN THE YEARLY THERMAL	
CITY	SISTEM	Total (kWh)	avings Cool (%)	avings Heat (%)	Total avings (%)	Cool ings (%)	Heat vings (%)
Madrid	Blueface	3903	30.7%	27.0%	8.3%	28.5%	21.1%
	Enerface	4368	20.4%	19.3%	9.7%	9.3%	6.6%
arcelona	Blueface	6567	32.4%	26.3%	9.0%	32.7%	30.3%
	Enerface	2624	14.9%	7.5%	0.8%	9.4%	2.7%
alencia	Blueface	3696	30.0%	30.8%	0.4%	30.6%	33.9%
	Enerface	5322	21.2%	5.3%	4.2%	12.1%	1.9%

Table 16: Percentage of power saving of zoned inverter systems with gateways Enerface and Bluface relferenced to a zoned inverter system

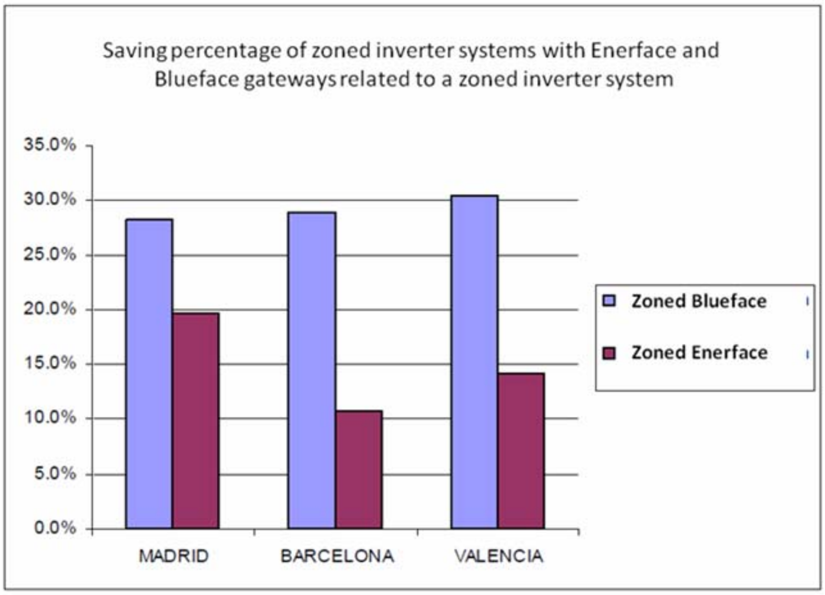


Figure 16: Comparison of annual energy savings of inverter systems with zoning and Enerface / Blueface Gateway related to a zoning inverter system

The results are as expected given that all actions are controlled by the energy management systems aim to reduce the thermal demand on the unit and improve its COP. The following are the conclusions drawn from the study data.

1. The inverter system with zoning and Blueface gateway provides around 45% savings on the annual thermal demand, when compared to a non-zoned inverter system with setpoint temperatures of 23 ° C (73 ° F) and 24 ° C (75° F) in winter and summer respectively. However, when compared with an inverter with integrated with zoning, but without any energy management, the annual savings on heat demand would total around 29%. This reduction in thermal demand translates into an annual power savings of around 45 % in reference to a non-zoned inverter unit and 30% compared to the inverter system integrated with zoning.

2. The inverter system with zoning and EnerFace gateway provides around a 30% savings on annual thermal demand, when compared to a non-zoned inverter with set point temperatures of 23 ° C (73 ° F) and 24 ° C (75° F) in winter and summer respectively. However, when compared with a zoned system with integrated inverter, but without energy management, the annual savings for heat demand would total about 7%. This reduction in thermal demand translates into an annual power savings of around 38 % in reference to

a non-zoned inverter unit and 15% compared to the inverter system integrated with zoning.

3. When comparing the annual power savings results achieved with the zoned system with Blueface and EnerFace gateway, it is verified that while in the zoned system with Blueface gateway the annual power savings are equal to the thermal demand savings, the power savings of the system with Enerface gateway are higher. This is because the equipment used in the simulations is sized to maintain the set point temperatures of 23 ° C (73 ° F) and 24 ° C (75 ° F) in winter and summer respectively. Thus, when the unit is set to work with set point temperatures of 21 ° C (70 ° F) and 26 ° C (79 ° F), appears to be somewhat oversized in certain parts of the year and forced to increase the number of time steps in which the team works as an on-off system. Thus, the zoned system with Blueface gateway fails to improve the efficiency factor of the unit. By contrast, the zoned system with EnerFace gateway that only interact with the unit in the time periods in which the unit works in a high regimen, it improves the efficiency coefficient of the unit, and the annual electrical savings are higher than the thermal demand.
4. In general terms, the Blueface system achieves greater annual power savings than the Enerface system, but that is achieved by reducing the user's comfort along the day. As shown in Figure 13, the difference in power savings between the two systems is lower in Madrid than in other locations. This is because Madrid has winter and summer with more compelling weather conditions, and for this reason the Enerface management system will find more applications in there. In coastal locations, such as Valencia and Barcelona, the winters are mild and therefore, if the HVAC is properly selected, it will be able to maintain the conditions defined by the user working mostly a at partial load. Thus, in these locations, the savings generated by the Enerface system are solely to periods when the unit is working in cold mode, while a Blueface, because it interact on the team regardless of its response, there will be significant savings in both operating modes

3 Conclusions.

The final conclusions of the study were described following:

1. The design of an inverter system with integrated zoning compared with an inverter not zoned, implies a reduction in thermal demand required, and therefore the possibility of selecting a smaller unit. This reduction in power is advisable to prevent an oversized unit, and therefore increase the number of time steps in which the same works as an on-off system. Thus, an inverter system with integrated zoning is able to reduce the initial cost of the installation.

2. The integrated inverter system with integrated zoning without bypass shows a power consumption yearly savings of about 2.5% compared to the same system with bypass

3. The inverter system with integrated zoning without bypass shows a yearly power consumption

savings of around 25% compared to an inverter system non-zoned.

4. The reduction in power consumption provided by the integrated zoning system,is also accompanied by a significant increase in thermal comfort of the user. While the inverter system with integrated zoning is able to maintain a comfort level above 90% in all areas, the not zoned inverter system is only able to maintain these levels in the control area

5. The zoned inverter system with Blueface gateway has an annual power consumption saving of about 45%, compared to the non-zoned inverter system, and 29% compared to an inverter system with integrated zoning.

6. The zoned inverter system with Enerface gateway presents an annual power consumption saving of about 38%, compared to the non-zoned inverter system, and 15% compared to an inverter system with integrated zoning.

7. The annual electric savings provided by the Blueface gateway is greater than the Enerface gateway, However, this is achieved penalizing the user comfort and maintaining the set point temperature fixed at 21 ° C (70° F) and 26 ° C (79° F) in winter and summer respectively

4. References.

[1] Manuel R. Conde, *"Bivalent Heating System with Air-Source Heat Pumps. A Simulation Exercise".* Energy Systems Laboratory. Institute of Energy Technology. Swiss Federal Institute of Technology, 1985.

[2] Hart,G.H., Goldschmidt, V.W., *"Field measurement of a mobil home unitary heat pump (in heating mode)".* ASHRAE Transactions, Vol 86/2, 1980.

[3] Yi-guang Chen, Xian-min Guo, *"Dynamic defrosting characteristics of air source heat pump and effects of outdoor air parameters on defrost cycle performance".* Applied Thermal Engineering 29 (2009) 2701-2707.

[4] Dong Huang, Quanxu Li, Xiuling Yuan, *"Comparision Between Hot-Gas Bypass Defrosting and Reverse-Cycle Defrosting Methods on an Air-to-Water Heat Pump".* Applied Energy 86 (2009) 1697-1793.

[5] Cai-Hua Liang, Xiao-Song Zhang, Xiu-Wei Li, Zhen-Qian Chen, *"Control Strategy and Experimental Study on a Novel Defrosting Method for Air Source Heat Pump".* Applied Thermal Engineering 30 (2010) 892-899.

[6] Luca Cecchinato, *"Part load efficiency of packaged air–cooled water chillers with inverter driven scroll compressors".* Energy Conversion and Management 51(2010)

1500-1509.

[7] Ernesto Bettanini, Alessio Gastaldello, Luigi Schibuola, *"Simplified models to simulate part load performance of air conditioning equipments",* Eighth International SFS Conference, Eindhoven, Netherlands, August 2003.

[8] Shuangquan Shao, Wenxing Shi, Xianting Li, Huajun Chen, "Performance *representation of variable-speed compressor for inverter air conditioners based on experimental data".* International Journal of Refrigeration 27 (2004) 805-815.

[9] Klein S.A., Duffie J.A. Beckman W.A. y otros, *"Trnsys 16: A transient system simulation program. Programmer's guide".* Solar Energy Laboratory, University of Wisconsin-Madison, 2007.

[10] Klein S.A., Duffie J.A. Beckman W.A. y otros, *"Trnsys 16: A transient system simulation program. Multizone Building modelling with Type 56 and TRNBuild".* Solar Energy Laboratory, University of Wisconsin-Madison, 2007.

[11] US Departament of Energy, *"Energy Plus v5.0 Engineering Reference".* University of Illinois of the Ernest Orlando Lawrence Berkeley National Laboratory, 2010.

[12] ASHRAE 2001, Handbook of Fundamentals. American Society of Heating Refrigeration and Air Conditioning Engineers, 2001.

[13] Norma UNE-EN 14511-3 de Diciembre de 2004, *"Acondicionadores de aire, enfriadoras de liquido y bombas de ca/or con compresor accionado electricamente para la calefaccion y refrigeracion de locales. Parte 3: Metodos de ensayo".*

[14] Datos Tecnicos RZQ-B Aplicacion Split/Twin/Triple/Doble Twin, con tecnologia inverter de Daikin, 2008.

[15] Hung I. Henderson et al., "Imrpoving DOE-2's RESYS Soutine: user defined functions to provide more accurate part load energy use and humidity predictions", Lawrence Berkeley National Laboratory.