AIRZONE
Smart climate control

Report on **the Airzone zoning model** and its comparison with a non- zoned system

uma
UNIVERSIDAD DE MÁLAGA

AIRZONE ZONED MODEL. CASE STUDY

1. Introduction

In industrialized countries the trend in living habits sees people spending most of their time in enclosed spaces, leading to significant changes in both the energy use that takes place within the building, and in the requirements of thermal and lighting comfort and indoor air quality, as well as how these services are managed. Directive 2012/27/EU [1] estimates that 40% of end energy consumption occurs in buildings, and that approximately 50% of this is attributable to cooling and heating systems.

The aim of this study is to demonstrate how the implementation of smart control systems in HVAC installations contributes effectively to the energy efficiency of a building. Specifically, the study focuses on the residential sector and on services with small and medium capacity AC units, where all-air systems equipped with direct expansion inverter units and constant-flow ductwork are commonly used. The Altra Corporation, through its Airzone division, aims to evaluate the advantages of a system of this type, from the point of view of occupant comfort, thermal demand and annual electrical consumption, with respect to a non-zoned conventional inverter system.

2. Airzone zoned control systems

In the residential and services sector with installations of small and medium capacity AC units, all-air systems equipped with direct expansion inverter units and constant-flow ductwork are commonly used. This kind of system is based on controlling the temperature of a single zone to ensure comfort levels are maintained in that area. With regard to the rest of the zones, even when the ductwork is well designed and the AC unit has the required maximum capacity, if the load profile is not similar to that of the control zone (use, orientation, thermal loads, etc.), their temperatures can fall outside the comfort range.

A **zoned system**, however, is based on independently controlling the temperature of each of the zones. To do this a thermostat is installed in each room, allowing the thermal demand for each of the zones to be determined, and the selection of an independent set-point temperature depending on the preferences of the user. In this way, when the set-point temperature established for the zone is reached, a control signal is sent to the zone's motorized damper which interrupts the airflow supply to that room. Figure 1 shows a diagram of a zoned system.

***Figure 1**. Diagram of a zoned system.*

In addition to thermal zoning, the Airzone control system bases its operations on a **communication gateway**. Achieving a high comfort level at the same time as reducing power consumption requires good communication between the zoning system and the AC unit. The communication gateway is the device that enables this two-way communication between the control board and the AC unit. Airzone has agreements in place with the main manufacturers to share the communication protocols used by their AC units. This makes it possible to have information about their operational parameters, so actions can be performed, such as:

- Switching the AC unit on or off.
- Changing the operating mode.

The AC unit's operating mode (cooling, heating or ventilation) is set by the installation’s master thermostat. Those zones that are in thermal inversion, that is to say, with a demand opposite to the AC unit's operating mode, will remain off.

- Controlling the indoor unit's fan speed.

This is regulated by the *Q-Adapt* algorithm, which adapts the airflow rate of the indoor unit's fan by changing its speed dynamically.

- Limiting the zone's set-point temperature.

This is regulated by the *Eco-Adapt* algorithm, which monitors the set-point temperature in the different zones and limits the maximum or minimum selectable temperature according to whether it is in heating or cooling mode, respectively. *Mode A* sets the maximum temperature range in winter at 22°C and in summer the minimum is set at 24°C, *Mode A+* at 21.5°C and 25°C, and *Mode A++* at 21°C and 26°C.

- Controlling the AC unit's set-point temperature.

This is regulated by the *Efi-Adapt* algorithm (*Eco-Adapt* functionality for air-to-air units), which dynamically controls the AC unit's set-point temperature based on the temperature in each zone and the return temperature to the AC unit, taking into account the effect of thermal inertia in each zone.

Figure 2 shows a diagram of a zoned ducted system in a building, with the control board and communication gateway.

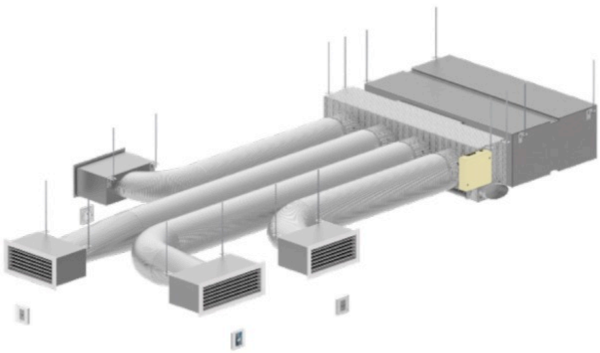


Figure 2. *Diagram of a zoned system*

3. Implementation of the models in TRNSYS

The present study has been modeled using the TRNSYS software [2], a benchmark program for research into thermo-energy installations. Mathematical models of all HVAC systems defined in the previous section have been run using this calculation platform. These models have been obtained through experimental tests of a direct expansion unit in a double climatic chamber. The idea is to determine the behavior of the AC unit within the range of working conditions to which it will be subjected in a real installation. This ensures we achieve good coupling between building and system (Figure 3).

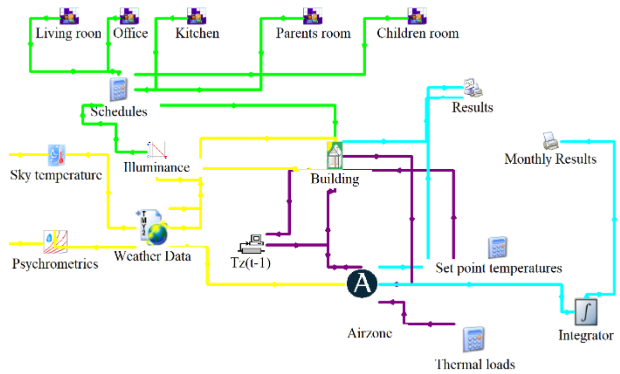


Figure 3. *Setting up the zoned system in TRNSYS.*

In the modeling of a direct expansion inverter unit, when characterizing the behavior of the AC unit, it must be taken into account that the operating mode, the AC unit's performance and the power consumption required will vary depending on the operating conditions. To this end, an AC unit of this type was used in the research and the different characteristic performance curves with their corresponding coefficients were obtained.

An inverter unit is capable of regulating its working regime in order to adjust the production of thermal energy to the demand. The partial load factor (PLR) is defined as the ratio between the sensitive load demanded and the maximum load that the AC unit is capable of providing under the same working conditions:

$$PLR = \frac{Q_{demand}}{Q_{sens,max}}$$

Figure 4 shows the three working regimes of an inverter unit with the evolution of the AC unit's performance according to the partial load factor.

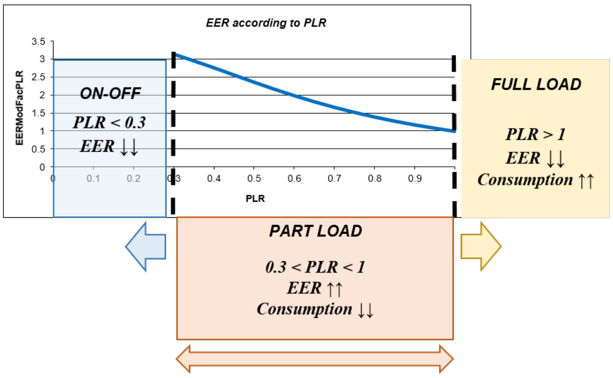


__Figure 4.__ Diagram showing the different working regimes of an inverter unit.

The working regimes are as follows:

- For PLR values lower than 0.3, as the refrigerant mass flow cannot be made arbitrarily small, there is a minimum speed at which the AC unit ceases to function as an inverter system, to become all/nothing.
- With PLR values between 0.3 and 1, the AC unit works at partial load and high EER values are obtained.
- With PLR values greater than 1, the AC unit works at full load and there is a significant decrease in performance.

4. Results. Case study

The objective of this study is to compare the advantages of a zoned inverter system with the different control configurations offered by Airzone, with a non-zoned inverter system. The criteria used for comparison are the annual electricity consumption and the comfort level provided by each of them. Thus, this section will be divided into two parts: on the one hand, the comfort levels provided are established, and on the other hand, the associated annual electricity consumption is examined.

Case study

The home under study (Figure 5) has five heated/cooled zones (living room, kitchen, office, parents' bedroom and children's bedroom), with a surface area of 121 m2, with the remaining area considered as a single zone without heating/cooling.

The simulation is carried out in different European cities: Milan, Paris, Munich and London.

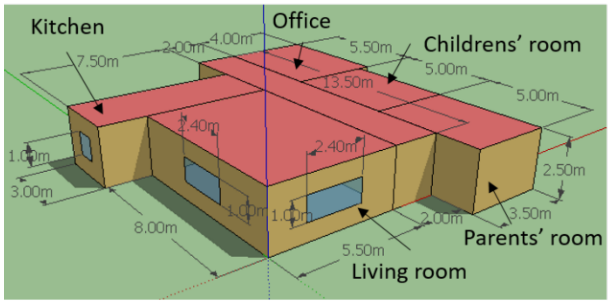


__Figure 5.__ Floor plan of the home. 3D representation with measurements.

The enclosures are representative of the different regulations prevailing in each country. Table 1 shows the values considered for the overall heat transfer coefficient of the different enclosures of the dwelling.

CITY	REGULATION	WALL	CEILING	FLOOR	WINDOW
Paris	RT 2005 [3]	0.24	0.658	0.658	1.14
Munich	EnEv 2009 [4]	0.28	0.2	0.35	1.3
London	Building regulations 2013 [5]	0.18	0.13	0.13	1.4
Milan	D. Lgs. N. 192 of August 19, 2005 [6]	0.34	0.33	0.3	2.2

__Table 1.__ Threshold U-values

A typical occupancy profile is applied in residential buildings to determine the calculation of internal gains: occupation, illumination and equipment (Table 2).

ZONE	LIVING ROOM	KITCHEN	OFFICE	CHILDREN'S ROOM	PARENTS' ROOM
	O/I/E	O/I/E	O/I/E	O/I/E	O/I/E
0:00-7:00	0/0/0	0/0/300	0/0/0	2/0/0	2/0/0
7:00-7:30	0/0/0	1/5/300	0/0/0	2/0/0	1/0/0
7:30-8:00	0/0/0	1/5/770	0/0/0	1/5/0	1/0/0
8:00-10:00	1/5/100	1/5/770	0/0/0	1/5/0	0/0/0
10:00-16:00	1/0/100	1/0/300	0/0/0	1/0/250	0/0/0
16:00-17:00	2/0/100	1/0/300	0/0/0	0/0/0	0/0/0

17:00-19:00	1/5/100	1/5/300	1/5/250	0/0/0	0/0/0
19:00-20:00	1/5/100	1/5/300	0/0/0	0/0/0	0/0/0
20:00-20:30	3/5/100	1/5/770	0/0/0	0/0/0	0/0/0
20:30-23:00	4/5/100	0/0/300	0/0/0	0/0/0	0/0/0
23:00-24:00	0/0/0	0/0/300	0/0/0	2/0/0	2/5/0

Table 2. *Home usage profile. (Activity rate EN ISO 7730:2005 [7]. O: Occupation, I: Illumination, E: Equipment)*

A rate of 0.6 renewals/hour is set for outdoor air ventilation flows in all rooms except the kitchen, which is set at 5.7 renewals/hour.

Calculation of loads. Sizing of the AC units

The sizing of the AC units is done taking into account that the user comfort range will be set between 22°C (T_{lower}) and 24°C (T_{upper}).

In a **non-zoned system**, the distribution network has no element that allows the system to deal separately with the needs of each zone. Therefore, to guarantee the possibility of meeting peak load in all zones, the performance rating of the AC unit must be equal to or greater than the sum of peak sensible loads of the zones, even if they are not simultaneous.

On the other hand, in a zoned system, the distribution network has motorized dampers that allows you to adjust the thermal contribution of the system to the demand of each zone separately. This means that the AC unit is sized by taking into account the maximum simultaneous sensible load of the zones. In other words, for every time step, the loads of all zones are added together, and the AC unit is sized based on the annual maximum for cooling and heating.

Table 3 shows the peak and simultaneous loads for the three cities.

SYSTEM		NON-ZONED	ZONED
CITY	LOAD (W)	PEAK	SIMULTANEOUS
Paris	Q_{COOL}	7646	6129
	Q_{HEAT}	-7793	-7883
Milan	Q_{COOL}	6423	4560
	Q_{HEAT}	-7607	-7648
London	Q_{COOL}	2315	4869
	Q_{HEAT}	-4548	-4929
Munich	Q_{COOL}	1374	1986
	Q_{HEAT}	-4339	-4671

Table 3. *Summary of thermal loads.*

Depending on the loads obtained, the AC units have been sized according to the different models of all-air systems equipped with direct expansion inverter units available in the market, as summarized in Table 4.

CITY/EQUIPMENT	ZONED	NON-ZONED
Paris	Model 6.0 kW	Model 6.0 kW
Milan	Model 7.1 kW	Model 7.1 kW
London	Model 5.0 kW	Model 5.0 kW
Munich	Model 5.0 kW	Model 5.0 kW

Table 4. *Sizing of the AC units*

As these are cities with very cold climates and very restrictive thermal transmittance values, the application of the zoned control system does not reduce the required capacity of the AC unit, so the comparative study is carried out on the same AC unit capacity in both cases.

Results. Thermal comfort

Evaluation of thermal comfort

The comfort results focus exclusively on the zone temperature comparison depending on whether the system is zoned or not.

The control of the zone temperature in a **non-zoned system** depends on the demand of the living room, which is the master zone where the AC unit's thermostat is located, and is regulated according to the set-point temperature established for this zone, while the thermal behavior of the remaining zones depends on the specific conditions (internal loads, solar gain, etc.) at that moment in time. Unlike the zoned system where the fan speed is selected using the Q-Adapt algorithm, in a non-zoned system the fan speed varies depending on the temperature difference between the master zone set-point temperature and the temperature of that zone. The graph in Figure 6 shows an example for a three-speed fan.

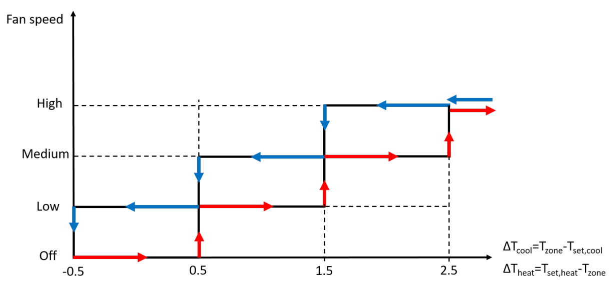


Figure 6. Selecting the fan speed for a non-zoned system.

Unlike a non-zoned system, with a zoned system, it is the user who decides the desired set-point temperature in each of the zones, and whether the operating mode is set to heating or cooling. Regarding the set-point temperature, the system establishes a comfort range of ±0.5°C, in such a way that a zone is in comfort when its temperature is within this defined range. This behavior is established to prevent the actuators from constantly changing their position in the event of slight temperature variations. Figure 7 shows the typical temperature behavior of the zone with zoned control in heating and cooling mode.

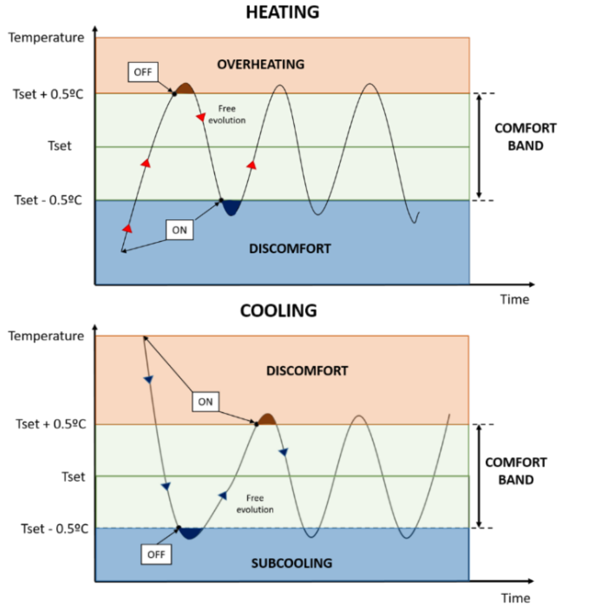


Figure 7. Evaluation of thermal comfort in a zoned system.

In order to be able to compare the zoned and non-zoned systems, the percentage of hours in which both systems are within a comfort range of ±1°C (Figures 8 and 9) will be compared for cooling and heating modes.

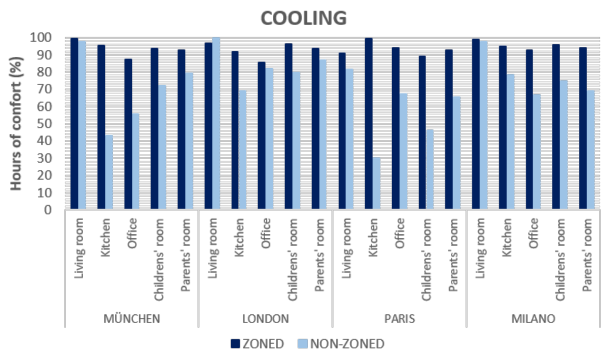


Figura 8. Comparison of the percentage of comfort hours in cooling mode.

The results show that in the four cities, the non-zoned system is able to maintain comfort in the living room zone, but the percentage of comfort hours decreases significantly in the rest of the zones due to the inability of the system to adapt the cooling capacity to each of the zones according to their thermal demand. On the other hand, the zoned system is capable of securing comfort in all zones independently, with values above 90% comfort.

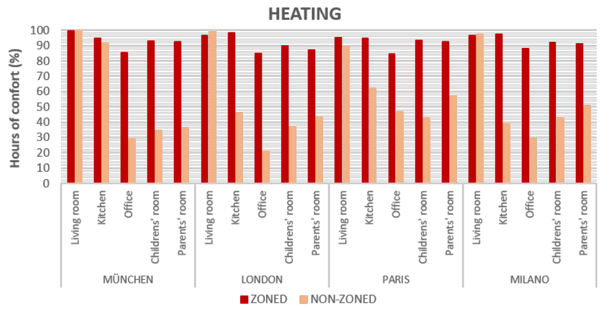


Figure 9. *Comparison of the percentage of comfort hours in heating mode.*

The conclusions for heating mode (Figure 9) are similar to those of the previous case, where the non-zoned system achieves high comfort in the living room zone with comfort decreasing in the remaining zones of the building. However, for the zoned system, a comfort percentage of less than 90% is obtained in the office zone due to the high thermal inertia that must be overcome because of the large number of hours without heating/cooling.

Thermal comfort label. Set-point temperature deviation

In order to take into account how far away the zone is from the comfort set-point in thermal terms, the so-called Comfort scale is defined. Similarly to the energy rating scale, this scale consists of an alphabetical designation in an interval [A,G], where A is the most favorable rating and G the most unfavorable, depending on the value of the comfort indicator (CI), obtained in each zone or in the building. This makes it possible to penalize comfort according to the difference between the zone temperature and the set-point temperature. Figure 10 shows the CI (%) of the building for different set-point temperature deviations for both zoned and non-zoned systems.

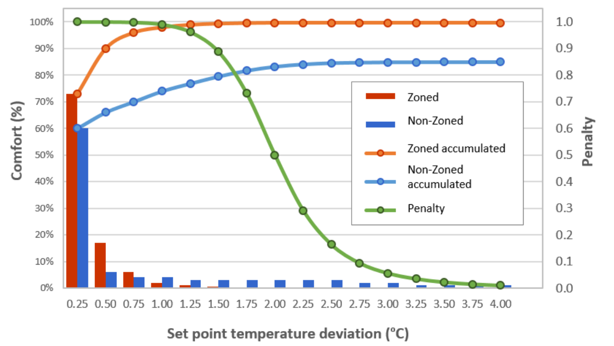


Figure 10. *Evaluation of the comfort indicator (IC).*

The CI is calculated using the following equation:

$$IC(\%) = \sum_{i=1}^{Ndesviaciones} Confort_{Edif,\Delta T=desviacion_i} \cdot Penalizacion_i$$

where the variable $Comfort_{Building,\Delta T}$ measures the deviation and the Penalty function (green curve in Figure 10) penalizes the comfort according to t_i which is the deviation i over the set-point temperature, i.e. the difference between the zone temperature and the set-point temperature.

The final scale obtained is shown in Figure 11.

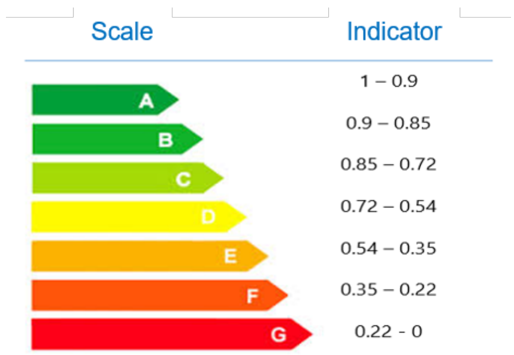


Figure 11. *Comfort scale based on the comfort indicator (IC).*

Below is the comparison of comfort in each of the areas of the building, in the four cities analyzed, given for heating mode, since cooling is less important in these cities, and based on the comfort scale.

Figure 12 shows the results of the comfort label for the living room area. In the comparison, for each month the zoned system (ZON) and a non-zoned system (NOZ) are compared.

Figure 12. Comparison of the comfort label for the living room, in heating mode.

It is observed that the differences in the comfort label between the zoned and non-zoned system for the living room zone are very small, since in the non-zoned system the master thermostat is in the living room and the system is able to maintain comfort in this area without problems. However, the comparison for the remaining zones of the building is shown below (Figure 13).

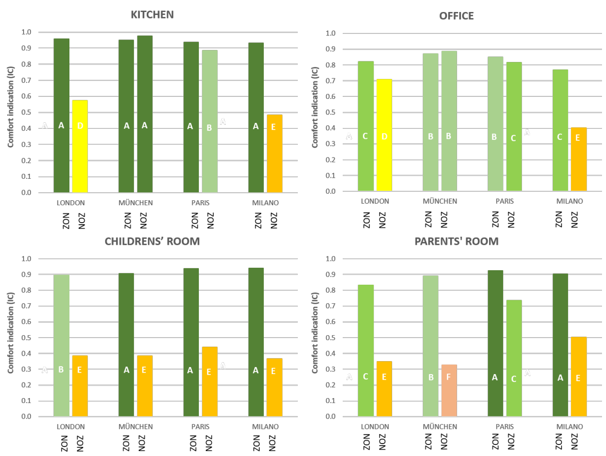


Figure 13. Comparison of the comfort label for the remaining zones of the building, in heating mode.

The results show notable differences in comfort between the two systems. In the non-zoned system, the labels are variable depending on the thermal characteristics of each zone, where overheating occurs, worsening the comfort label. On the other hand, in the zoned system, an excellent comfort level is generally obtained with an A label, and there is always a CI that is higher than the non-zoned system.

Lastly, Figure 14 shows the overall average comfort of the building, in heating mode.

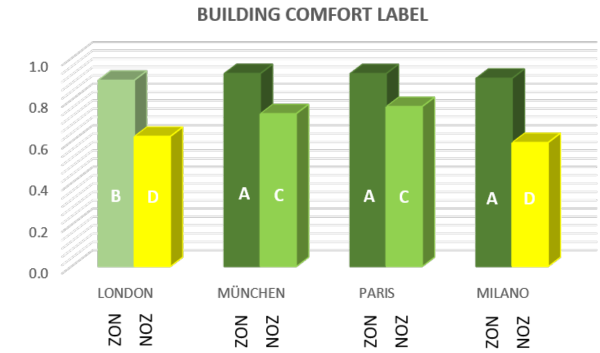


Figure 14. Comparison of the overall comfort label for the building.

The building's overall label for a zoned system is A in all cities except London, where we get a B label, whereas the non-zoned system gets C and D labels.

Comfort parameters: PMV and PPD

In standard conditions of comfort associated with levels of clothing, metabolic rate and relative air speed, a comparison was made of the PPD and PMV parameters in a zoned and non-zoned system, in accordance with European standard EN ISO 7730:2005 [7]. According to this standard, the recommended values for providing overall thermal comfort to 90% of users are those shown in Table 5.

CATEGORY	PPD (%)	PMV
A	< 6	-0.2 < PMV < 0.2
B	< 10	-0.5 < PMV < 0.5
S	< 15	-0.7 < PMV < 0.7

Table 5. Thermal environment categories according to PPD and PMV

Figure 15 shows the comparison of the PPD parameter, highlighting the category of comfort obtained.

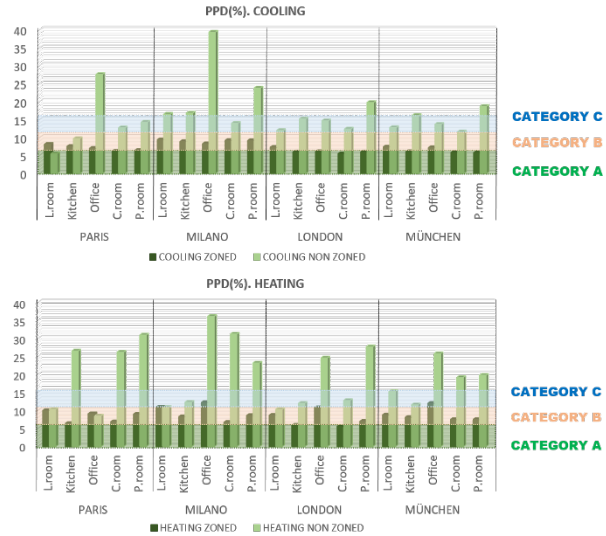
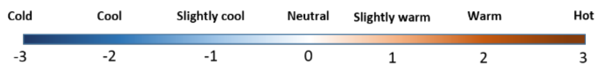


Figure 15. *PPD comparison.*

The PMV results are shown in Table 6, where color codes have been used to facilitate a more immediate comparison of the results.



CITY	ZONE	PMV			
		COOLING		HEATING	
		ZONED	NON ZONED	ZONED	NON ZONED
MILANO	Living room	-0.3	-0.5	0.5	0.5
	Kitchen	-0.2	-0.7	0.4	1.0
	Office	-0.2	-0.8	0.6	0.4
	Childrens' room	-0.2	-0.5	0.3	1.6
	Parents' room	-0.2	-0.8	0.4	1.1
PARIS	Living room	-0.2	-0.1	0.4	0.5
	Kitchen	-0.2	0.3	0.2	1.0
	Office	-0.3	-1.0	0.5	0.4
	Childrens' room	-0.1	-0.3	0.3	1.6
	Parents' room	-0.1	-0.5	0.4	1.1
LONDON	Living room	-0.3	-0.5	0.4	0.4
	Kitchen	-0.2	-0.6	0.3	0.3
	Office	-0.2	-0.6	0.4	0.7
	Childrens' room	-0.2	-0.5	0.2	0.5
	Parents' room	-0.2	-0.6	0.3	1.0
MÜNCHEN	Living room	-0.2	-0.4	0.4	0.7
	Kitchen	-0.1	-0.7	0.3	0.1
	Office	-0.3	-0.6	0.4	1.1
	Childrens' room	-0.1	-0.4	0.2	0.7
	Parents' room	-0.1	-0.4	0.2	0.8

Table 6. *PMV comparison*

In a zoned system, the minimum comfort requirements demanded of category B with a PPD lower than 10% and a PMV below 0.5 are met in each of the areas of the home for the four cities modeled, while the non-zoned system obtains good results in the living room zone, but the rest of the zones experience significant undercooling in zones in cooling mode and overheating in heating mode.

Results. Energy consumption.

After evaluating the building's thermal comfort, the next step is to compare the power consumption of a zoned and non-zoned HVAC system. Thanks to the Airzone system's strategies designed to control and manage the HVAC installation, energy savings are achieved and therefore also a reduction in carbon emissions. Figure 16 shows the results obtained for the comparison of these systems for the different cities under study.

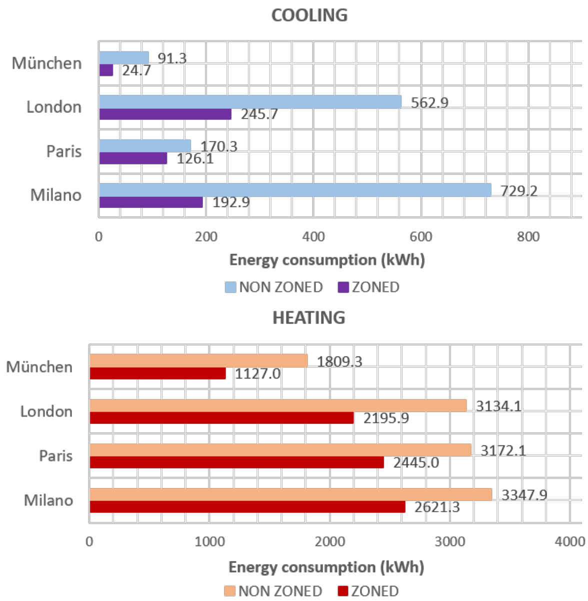


Figure 16. *Comparison of energy consumption in cooling and heating modes.*

In all cases the HVAC consumption is lower in a zoned system than in a non-zoned system. The values obtained are within the maximum consumption limits established by the different regulations in force. The reasons have been explained in detail in this report: Reducing the thermal capacity of the HVAC system, regulating the fan speed and adapting the set-point temperature of the AC unit using the Eco-Adapt function. The differences in consumption are clearly reflected in the savings obtained in each of the cases, as shown in Figure 17.

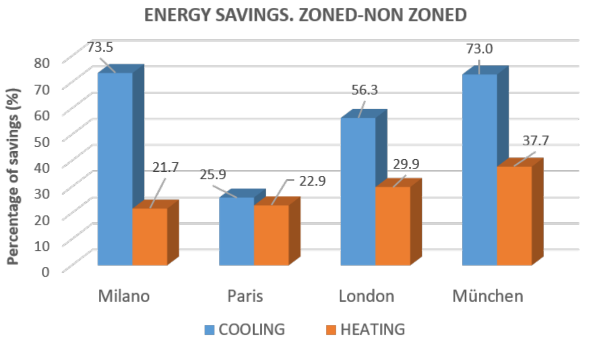


__Figure 17.__ Percentage of energy savings in heating and cooling modes.

In the four cities under study, there are important savings achieved in HVAC. In cooling mode the savings percentages are higher, reaching values of 73% in Milan and Munich, but the consumption values are less important. However, in heating mode, it should be noted that in Milan and Paris the savings are 21-22%, whereas London and Munich reach values of 30 and 38%, respectively.

Lastly, the potential for energy savings of the Eco-Adapt algorithm was assessed for the four cities modeled. These results are expressed graphically in Figure 18, making it possible to verify the different steps to improve energy efficiency shown by the zoned inverter systems studied.

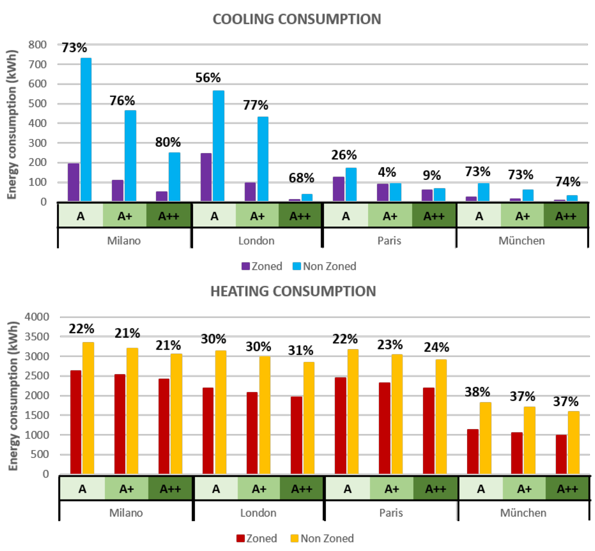


__Figure 18.__ Comparative energy consumption using the Eco-Adapt function.

With the application of the Eco-Adapt algorithm a reduction in energy consumption was achieved, depending on whether the set-point temperature was increased in cooling mode or decreased in heating mode. The savings are 22-37% in heating mode, whereas in cooling mode high percentage values are achieved, but with lower absolute values.

5. Conclusions

The aim of this study is to analyze in detail the behavior of Airzone's HVAC control system based on thermal zoning and compare it with a non-zoned system. The document is structured in different sections in which the zoning system and the control algorithms are described, and it explains the modeling of the AC unit with the behavior curves at partial load obtained experimentally, and the implementation of the model of the direct expansion unit with the Airzone control system in the TRNSYS software, which will be the simulation environment of the study.

The final conclusions of the study describe the main advantages obtained in the different comparisons made between a zoned system and a non-zoned system in terms of thermal comfort, energy consumption and thermal energy. The conclusions are defined below:

1. The specification of an inverter system with integrated zoning as opposed to a non-zoned inverter system, implies a **reduction of the thermal energy** to be combated, and therefore the possibility of adapting the AC unit's capacity more accurately to the thermal demand. In cities with cold climates with low thermal transmittance values, reductions in thermal demand are obtained, although, unlike in other climates, they are not significant enough to reduce the capacity of the AC unit.

2. The zoned system monitors the temperature in each of the building's zones and allows the user to set their comfort preferences in each zone. It has been demonstrated that, when compared to a non-zoned system, the percentage of hours in which the zones are in **thermal comfort** is much higher in a zoned system.

✓ In a first analysis, a comparison is made with **a comfort range of ±1°C** in Paris, Milan, London and Munich. The results show that in the four cities, the non-zoned system is able to maintain comfort in the living room zone, but the percentage of comfort hours decreases significantly in the remaining zones of the building. On the other hand, the zoned system is capable of securing comfort in all zones independently.

- ✓ The concept of the **comfort label** is introduced and used to evaluate thermal comfort by penalizing, over a given period of time, the comfort level when the temperature is farther away from the set-point temperature established. The building's overall comfort label for a zoned system is A in all cities except London, where it is rated as B, whereas the non-zoned system achieves C and D labels.

- ✓ Finally, to complete **the comfort study, the PPD and PMV parameters** are calculated. In a zoned system, the minimum comfort requirements demanded of category B with a PPD lower than 10% and a PMV below 0.5 are met in each of the areas of the home for the four cities modeled, while the non-zoned system obtains good results in the living room zone, but the rest of the zones experience significant undercooling in zones in cooling mode and overheating in heating mode.

3. The comparison of power consumption between a zoned and non-zoned HVAC system has shown significant **energy savings**, mainly in heating mode, as these are cities located in cold climates.

- ✓ In the four cities under study, there are important savings achieved in HVAC. In cooling mode, consumption is low and the zoned system achieves savings of up to 73% in Milan and Munich. In heating mode, savings range from 21-22% in Milan and Paris, to 30-37% in London and Munich.

- ✓ The most important result extracted from the application of the Eco-Adapt algorithm is a reduction in the energy consumption depending on whether the set-point temperature was increased in cooling mode or decreased in heating mode. It is worth highlighting the 21-38% savings achieved in heating in the four cities analyzed.

References

[1] European Commission. Directive 2012/27/EU of the European Parliament and of the Council of October 25, 2012 on Energy Efficiency. Official Journal of the European Union (2012), L 315/1.

[2] TRNSYS http://sel.me.wisc.edu/trnsys/. (Accessed on January 2, 2018).

[3] The Réglementation Thermique 2012 (RT2012) (www.rt-batiment.fr). (Accessed on April 18, 2019).

[4] EnEV 09 (http://www.enev-online.org/enev_2009_volltext/index.htm). (Accessed on April 18, 2019).

[5] The Building (Amendment) Regulations 2013 (3rd June 2013). (http://www.legislation.gov.uk/uksi/2013/1105/contents/made). (Accessed on April 18, 2019).

[6] D. Lgs. N. 192 of August 19, 2005. Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia. http://www.parlamento.it/parlam/leggi/deleghe/05192dl.htm

[7] European standard EN ISO-7730:2005. Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.